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FOURTH SERIES

Bulletin M 27

MANGANESE MINERALS

OF

PENNSYLVANIA

By

RICHARD M. FOOSE

DEPARTMENT OF INTERNAL AFFAIRS
WILLIAM S. LIVENGOOD, JR., *Secretary*

TOPOGRAPHIC AND GEOLOGIC SURVEY
GEORGE H. ASHLEY, *State Geologist*

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LETTER OF TRANSMITTAL

April 18, 1945.

William S. Livengood, Jr.,
Secretary, Department of Internal Affairs.

Dear Mr. Livengood:

On June 7, 1939, the Congress of the United States passed the Strategic Minerals Act which listed all the metals that were then of strategic importance to the country. Manganese was the most needed metal on the list. On January 30, 1940, the Army and Navy Munitions Board approved the following definition of strategic materials and placed manganese on the list: Strategic materials are those essential to national defense, for the supply of which in war dependence must be placed in whole, or in substantial part, on sources outside the continental limits of the United States; and for which strict conservation and distribution control measures will be necessary.

Manganese is the alloy metal most urgently required by the country's iron and steel industry, and it is one of the most deficient in domestic production. Considering all grades of manganese ore that are used in metal production, the United States supplied about 12 percent of its needs in 1940 and imported 88 percent. In 1943, even after domestic production had been stimulated, this country supplied only 14 percent of its increased needs. Because the importation of vital raw materials is never as certain as established domestic production, and is especially precarious in times of emergency, manganese is a strategic metal. Since 1939, an intensive program of exploration has been carried on for manganese deposits by the United States Geological Survey and other organizations.

In the late spring of 1941, the Pennsylvania Geological Survey began investigation of the manganese minerals of Pennsylvania with a view to presenting complete and accurate information on all the manganese mineral localities in the State, and a detailed description of the geology and ore deposits of all areas that would hold any promise of commercial exploitation.

Dr. Richard M. Foose, senior geologist of the State Survey, has investigated the manganese mineral localities of the State, has made an exhaustive study of the occurrence and character of the manganese minerals, and has written the accompanying report, which is offered for publication as Bulletin M 27.

The section on identification of the manganese oxide minerals includes considerable new data and represents original research in a field about which there has been serious confusion for many years. The main results of this work were accepted in 1942 by The Johns Hopkins University in fulfillment of the requirements for the degree of Doctor of Philosophy and they constitute a significant contribution to the knowledge of these minerals.

Yours very truly,
GEO. H. ASHLEY,
State Geologist.

MANGANESE MINERALS OF PENNSYLVANIA

By Richard M. Foose

INTRODUCTION

PURPOSE AND SCOPE OF THE REPORT

The report has been prepared with two fundamental ideas in mind: 1. To describe the manganese minerals, how and where they occur, in such manner that the people of Pennsylvania will understand what they are, what their importance is, and will be interested in furthering the knowledge of manganese mineral resources in the State; 2. To treat fully the occurrence of the manganese minerals in Pennsylvania, including their geology, their mineral associations, their paragenetic relations, and to describe thoroughly those areas in the State which may have commercial value, so that the report will have scientific and practical value beyond the point of being solely a descriptive catalogue.

The area under consideration is the entire State of Pennsylvania. Field work was carried on by the writer continuously from June till October 1941; additional field investigations were made during the winter months of 1941-42, the fall of 1943, and several days during 1944. Laboratory investigations of the manganese minerals occupied the months from October 1941 to April 1942, March 1944 and part of December 1944.

Nearly every locality that has ever been reported as a manganese mineral locality, including those mentioned in the Second Geological Survey publications, has been visited and is described in this report. The report includes a more complete account of the geology and ore deposits in areas that have possible commercial value. Places that may warrant prospecting are mentioned and, for some, definite recommendations are made.

The manganese minerals as a group are discussed and described and special reference is made to the problem of identifying the manganese oxides. The types of manganese mineral occurrence in Pennsylvania are classified and discussed.

The report further includes a discussion of the economics of manganese, its strategic position, and the possible role of Pennsylvania in future domestic manganese production.

Acknowledgments

Investigation of many of the manganese mineral localities in the State was made possible by the generous help and coöperation of property owners and interested persons. Special thanks are due Mr. Harry Simon and Mr. James Simon, part owners of the manganese property in Sherman Valley, Bedford County, both of whom gave

cheerfully of time and information during the investigations. Mr. James Simon aided in the geologic mapping of the area.

The aid of geologists of the United States Geological Survey is thoroughly appreciated. Dr. D. F. Hewett willingly gave advice and information during the field investigations. The writer has also benefited by the use of certain chemical tests and X-ray determinations made by M. Fleischer, C. F. Park, Jr., W. Richmond, and others during their research on the manganese oxide minerals at the U. S. Geological Survey.

Dr. Joseph Hickman of the Chemistry Department, The Johns Hopkins University, kindly prepared two X-ray photographs of manganese minerals.

The use of a reference collection of polished sections of manganese minerals was extended to the writer through the kindness of Prof. George A. Thiel, of the University of Minnesota. Dr. Robert D. Butler, of Lehigh University, helped prepare many of the polished sections used for study. Several of the polished sections were loaned to the writer by the American Cyanimid Company.

During the laboratory study of the manganese minerals, the author enjoyed constant use of the equipment of the Department of Geology at The Johns Hopkins University, and helpful advice from the entire staff and student associates.

The writer takes pleasure in acknowledging the constant interest of all members of the staff of the Pennsylvania Geological Survey and the many suggestions they have made. Mr. Marchant N. Shaffner, of the Survey staff, helped during plane table mapping of the Reading Banks Pit, and Mr. Homer Ashton assisted the writer for three weeks during the mapping of the Sherman Valley area.

Finally, grateful acknowledgment is made to all those, too numerous to mention, who have materially aided this investigation in both field and laboratory.

Previous Work

There has been no prior comprehensive work on the manganese minerals of Pennsylvania.

In 1828 the occurrence of black oxide of manganese near the mouth of Sandy Run, three miles from Bustleton, northeast of Philadelphia was mentioned.[1] H. D. Rogers noted small quantities of manganese in the spathic iron ores of the Carboniferous rocks.[2] The publications of the Second Geological Survey of Pennsylvania have many analyses of iron ores that show manganese content, and they mention manganese mineral accumulations at some places.

Penrose[3] briefly mentioned the manganese deposits of Pennsylvania in 1891. Harder[4] summarized the general knowledge of manganese deposits in Pennsylvania in 1910. In 1922 Miller[5] prepared a short account of manganese mineral occurrences in the eastern part of the

[1] Carpenter, G. W., Am. Jour. Sci., 1st ser., vol. XIV, pp. 4, 12, 1828.
[2] Rogers, H. D., Geology of Pennsylvania, vol. II, p. 739, 1858.
[3] Penrose, R. A. F., Jr., Manganese: its uses, ores, and deposits: Arkansas Geological Survey, Ann. Rept., pp. 400-401, 1891.
[4] Harder, E. C., Manganese deposits of the United States: U.S.G.S. Bull. 427, pp. 42, 93, 94, 275, 1910.
[5] Miller, B. L., Manganese occurrences in eastern Pennsylvania: Penna. Topog. & Geol. Survey Bull. 47, 11 pages, 1922.

State, especially in connection with the iron ores of Lehigh and York counties. Most of the known localities were listed by Miller and analyses of the ores were presented for many of them. This work was largely a compilation but was enhanced by the author's many field investigations in Pennsylvania. Corbin[6] described some of the brown ores of the State, a number of which contained manganese.

Though the preceding literature represents the extent of existing information on manganese minerals in Pennsylvania, more complete work has been done in some of the other Appalachian States where the occurrence of many manganese deposits is similar. All of this work has been freely consulted and some of it has been a considerable aid to the preparation of this report.[7]

STRATEGIC POSITION OF MANGANESE*

Manganese is one of the most important metals used in the United States. During normal times, and especially during times of national

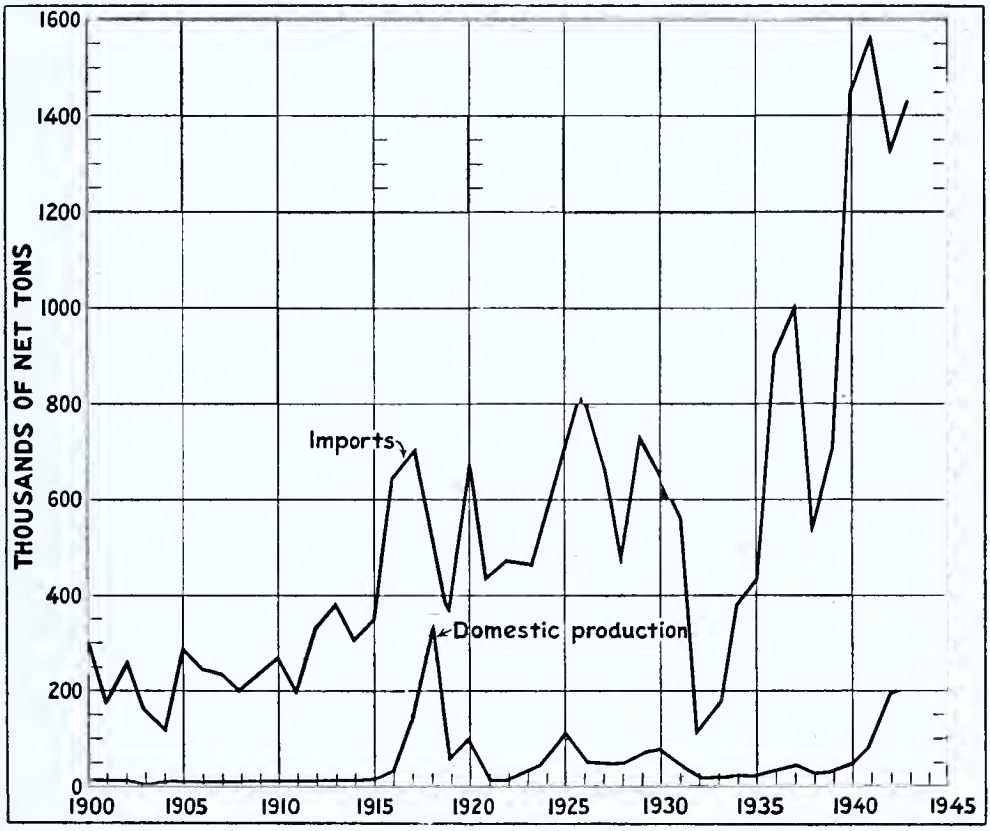

Figure 1. Graph showing the relative amounts of manganese ore imported and produced domestically.

[6] Corbin, J. R., Brown iron ores of Pennsylvania: Penna. Topog. & Geol. Survey Bull. 63, 8 pages, 1923.

[7] Stose, G. W., Miser, H. D., Katz, F. J., and Hewitt, D. F., Manganese deposits of the west foot of the Blue Ridge, Virginia: Va. Geol. Survey Bull. XVII, 166 pages, 1919.
Stose, G. W., and Miser, H. D., Manganese deposits of western Virginia: Va. Geol. Survey Bull. XVIII, 206 pages, 1922.
Stose, G. W., and Schrader, F. C., Manganese deposits of East Tennessee: U.S.G.S. Bull. 737, 154 pages, 1923.
Reichert, S. O., Manganese resources of East Tennessee: Tenn. Div. of Geol. Bull. 50, 204 pages, 1942.
Watson, T. L., The manganese ore-deposits of Georgia: Econ. Geol., vol. 4, pp. 46-55, 1909.

* Most of the pertinent statistics quoted in this section of the report are taken from Minerals Yearbooks, Reviews of 1940 and 1943.

emergency, it plays a vital role in the highly mechanized industry and the production of industrial products in this country.

Approximately 96 percent of all manganese ore used in this country is used by the steel industries. The remaining minor amount is utilized in chemical and other industries. The fundamental importance of steel to a highly mechanized and industralized country is obvious, and in times of national emergency, the importance is paramount. In 1940 domestic high-grade ore supplied about 3 percent of this country's needs (fig. 1). Because more than 95 percent of the present demand for high-grade ore must be supplied from foreign sources and because it is impracticable to substitute other metals for manganese in the role it plays in the steel industry, the metal is a vital one, and manganese ore is one of the country's most strategic raw materials.

Use of Manganese

Manganese is used in steel metallurgy as a scavenger to improve the final product so it may be used under a greater variety of conditions, and also to increase the facility of working the steel in forging, rolling, and other processes incident to the final product. Varying quantities of manganese are necessary for the preparation of different kinds of steel, like rimming steel and various killed steels, but all types require a sufficient quantity to deoxidize and desulphurize the molten mass. Approximately 12.5 pounds of manganese are needed for this purpose in the preparation of every ton of steel. Contrary to common belief, relatively little manganese is used in alloy products, for they are not considered manganese-alloy products unless the content of manganese exceeds 1.65 percent,[8] though the presence of less than this amount will impart valuable properties of hardness and toughness to the steel. The preparation of Hadfield steel, which contains 11 to 14 percent of manganese, and various special cast steels, requires only about five percent of the manganese used in the steel industry.[9]

The manganese products utilized in the steel industry for deoxidation and desulphurization work are chiefly ferromanganese and spiegeleisen.

Ferromanganese is an alloy containing 80 percent of manganese, 12 to 16 percent of iron, and about 7 percent of carbon. A manganese-iron ratio of about 8:1 is usually maintained. It is prepared from high-grade metallurgical ores. About 2 tons of ore, averaging more than 35 percent of manganese, are needed to prepare one ton of ferromanganese. In 1943 approximately 700,000 short tons of ferromanganese were produced in the United States and that represented more than 80 percent of the total amount of imported and domestic manganese ore averaging more than 35 percent. Ferromanganese is the best manganese product to add to the ladle in the preparation of iron and steel as it causes very little cooling. Some products, prepared and marketed as ferromanganese, contain much less manganese.

Spiegeleisen is an alloy containing 20 percent of manganese, about 5 percent of carbon, a little silicon, and the remainer iron. It is used as a substitute for ferromanganese and has wide application in the

[8] Steel Products Manual, American Iron and Steel Institute, sec. 9, New York, 1940.
[9] Rogers, B. A., Utilization of manganese in the steel industry: Bur. Mines I. C. 7162, April 1941.

steel industry. In 1943, 149,000 short tons of spiegeleisen were produced in this county, and all of it was manufactured from domestic ore. Only 3,000 tons of spiegeleisen were imported. Ferruginous manganese ore, ranging between 10 and 35 percent of manganese, was used in the manufacture of most of the spiegeleisen.

Besides the two alloys mentioned, other manganese products are also used in the steel industry.

Electrolytic manganese and manganese metal made in an electric furnace, containing more than 95 percent of manganese, have the same use as ferromanganese. They can be made from low-grade manganese ores. Though their present use is small, the use of electrolytic manganese will probably increase.

Manganiferous pig iron, which contains about 5 percent of manganese, is prepared from low-grade ores and may be used for similar purposes when supplemented by spiegeleisen and ferromanganese. Manganiferous pig iron also finds wide use in the preparation of certain cast iron products requiring a small percentage of manganese. Ores containing from 2 to 10 percent of manganese are suitable for the preparation of manganese pig. In 1940 more than 1,500,000 tons of domestic ore of this grade were produced.

In addition to the uses in the steel industry, manganese ore that averages more than 50 percent of manganese is used in the manufacture of dry-cell batteries. Some manganese oxide compounds are used in glass making, in the manufacture of chlorine and bromine, and as a drier in paints and varnishes. Very small quantities are also used as pigments in pottery and brick manufacture.

Economics of Manganese Ores

Classification. Manganese ore is classified as *battery* ore and *metallurgical* ore. Most battery ore must contain a high percentage of MnO_2, usually between 70 and 80 percent, and is generally classified as more than 50 percent ore. There is little domestic battery ore in the United States, the only source of any importance being the Butte-Philipsburg region in Montana.

Metallurgical ore is all used in ferrous metallurgy and is divided into four classes:

1. *Manganese ore* contains more than 35 percent of manganese.
2. *Ferruginous manganese ore* contains between 10 and 35 percent of manganese.
3. *Manganiferous iron ore* contains between 5 and 10 percent of manganese.
4. *Manganiferous zinc residuum.* The manganese-rich residuum of New Jersey zinc ores.

Prices. The value of manganese ore depends on its mineralogical nature as well as on its purity and manganese content. Prices paid for ores of medium grade, for which the demand is greatest, are relatively stable, but the value of high-grade ores, consumed in smaller quantities for special purposes, fluctuates greatly.

Prices of manganese ore are on a unit basis, in which the unit is one percent of a long ton, or 22.4 pounds of manganese metal. The monthly price quotations for all ores may be found in Engineering and Mining Journal. During 1943 the prices for metallurgical ore containing more than 35 percent of manganese averaged nearly 80 cents per long ton unit, and for standard 48-percent ore, the price was $1.00 per long-ton unit ($48.00 per long dry ton).

Though prices did not suddenly rise to great heights during World War II as they did in 1917, some conditions are similar to those of World War I. The general rise in price encouraged the re-opening and operation of many small, marginal deposits of manganese ore, worth little or nothing during normal times; it also encouraged the activities of promoters and speculators.

Salable ore was limited by rigid specifications in 1918 when the Government fixed prices. The same specifications are more or less applicable today. They are based on ore containing not more than 8 percent of silica and not more than 0.25 percent of phosphorus. Penalties may be imposed on ore exceeding these specifications. Manganese ore containing more than 25 percent of silica can seldom be used. During 1942-1945, there were many stock piles of low-grade manganese ore that were not salable.

Ore production. In 1943 the United States produced 1,928,041 short tons of all grades of manganese ore, excepting manganiferous zinc residuum. Of this, only 195,096 short tons contained more than 35 percent of manganese. Imports of more than 35 percent ore totaled 1,429,599 short tons.

In 1940 Pennsylvania produced a total of about 1,000 long tons of ferruginous manganese ore, of which 250 tons were shipped to furnaces. There was no production of ore containing more than 35 percent of manganese. There was no production of any grade of manganese ore in 1941, nor from 1943 to 1945.

Table 1 shows the available statistics for the production of manganese ore in Pennsylvania.

Table 1. Production of manganese ore in Pennsylvania in long tons

Year	Manganese ore	Ferruginous manganese ore	Total
1888	22		22
1895	460		460
1896	265		265
1897	354		354
1898		100	100
1899	12		12
1920		150	150
1921		50	50
1922		50	50
1923		150	150
1940		1000	1000
1942	23		23
			3136

Future of Pennsylvania as a manganese ore producer. The record of Pennsylvania as a producer of manganese ore is not bright. What of the future?

It has been pointed out that manganese metal is one of the most essential to the industrial well-being of the United States. Though, in times of emergency, manganese used as an alloy metal might be replaced by other metals, such as nickel and chromium, its use as a de-oxidizer and recarburizer in the metallurgy of steel is not easily replaced. Zirconium and titanium are the two elements which best fulfill the needs that manganese meets in steel metallurgy.[10] However, both of these elements would cost more to use than manganese at present prices; further, it would probably be impossible to obtain sufficient zirconium and difficult to obtain sufficient titanium except by imports.[11] Therefore, it appears that manganese will continue to occupy the same prominent strategic position it holds today.

When importation of manganese ores becomes difficult, an increased burden of supply must necessarily devolve upon domestic ore resources. There are few high-grade ore deposits in the United States. Two localities in Pennsylvania have high-grade ore which can be mined, and one of them has proved reserves.[12] Other localities, if properly explored and developed, might produce ore containing more than 35 percent of manganese.

Since deposits of true manganese ore are insufficient to supply domestic needs, one answer to the difficulty can be the treatment of low-grade ores with new milling methods to manufacture a suitable product for the steel industry. Spiegeleisen and electrolytic manganese can be prepared from low-grade ores. Though it is not possible to substitute spiegeleisen for ferromanganese in every case, it can be substituted in many cases, as it was during the crisis in World War I. Therefore, Pennsylvania is able to contribute to a program of production of low-grade ores. Though ore reserves in sight are small, a limited production could probably be assured. In view of the central industrial position of the State and the presence in the State of furnaces manufacturing both spiegeleisen and ferromanganese, it is reasonable to assume such a program would encourage exploration for and development of low-grade deposits.

The national emergency for manganese ore during World War II was fairly well met by 1943. During future peace-time years, it seems unlikely that Pennsylvania will produce much low-grade manganese ore, unless a long range national program is followed for the exploitation and stock-piling of low-grade deposits of mineral resources in which the nation is not self-sufficient.

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[10] Metal Progress, Ductile steel made without manganese: vol. 19, June 1931.
Ritchie, S. B., Steels made without manganese: Metal Progress, vol. 20, pp. 35-39, Sept. 1931.
Titanium Alloy Mfg. Co., Titanium and its use in steel (booklet): Niagara Falls, N. Y., 1940.

[11] Rogers, B. A., op. cit.

[12] Foose, R. M., Iron-manganese ore deposit at White Rocks, Cumberland Co., Penna.: Pa. Geol. Sur. Bull. M26, 1945.

THE MANGANESE MINERALS

GENERAL DISCUSSION

There are more than one hundred known manganese minerals.[13] These include oxides, carbonates, silicates, sulphates, sulphides, chlorides, phosphates, tungstates, tantalates, borates, arsenates, and antimonates. The oxides comprise by far the most important group of manganese minerals and the carbonates and silicates are next in importance. The other minerals are not common or are very rare. With minor exceptions, manganese oxides are the only minerals to be found in Pennsylvania.

The diversity of manganese minerals can be partly explained by the properties of the metal manganese which is never found in a free state. As a metal, free from carbon, manganese is reddish-grey, has a melting point of 1260°C., a specific gravity of 7.2 and a range of positive valence from 2 to 7. The wide range of valence gives rise to many of the different manganese minerals.

Under acid conditions, divalent manganese possesses great stability. For this reason, where acid conditions have maintained during the deposition and formation of manganese minerals, the divalent form, manganosite, may be the final one, the higher oxidized forms like braunite, hausmannite, manganite, and psilomelane being reduced to the more stable condition. Under neutral or alkaline conditions the divalent form is less stable and higher oxidized forms of manganese commonly exist in such places. Experiments[14] have shown the tetravalent form, pyrolusite, to be the most stable under neutral or alkaline conditions. The lower form may commonly be oxidized to a tetravalent state. Further experiments show the trivalent state, including common manganese minerals like manganite and psilomelane, is stable under conditions of excess acid, and the hexavalent state is stable under conditions of excess alkali. Heptavalent manganese is reduced only by some reducing agents and has great stability. The natural conditions influencing manganese mineral deposition and formation vary greatly, and make the many existing manganese minerals, especially the oxides, better understandable.

The most common manganese minerals are the oxides. There are five pure and distinct manganese oxides. They are: MnO, Mn_2O_3, MnO_2, Mn_3O_4, and Mn_2O_7. The first four are represented by well-known manganese minerals. Manganosite, MnO, is a rare manganese mineral associated with hausmannite in the Swedish manganese ores. Manganite, $Mn_2O_3H_2O$, is known for its occurrence at Ilefeld, Germany; psilomelane, a hydrated form with many impurities, is common. Pyrolusite and "polianite," MnO_2, are common manganese minerals. The former, especially, is the chief ore of manganese.[15] Hausmannite, Mn_3O_4, occurs at many places, but it is not common. The last oxide, Mn_2O_7, is the unstable anhydride of permanganic acid $HMnO_4$, and has no mineral representative.

Usually included in the oxide mineral group are the mixed oxides and the mixed oxide-silicates. Braunite, $3Mn_2O_3.MnSiO_2$, is an im-

[13] Dana lists 109.
[14] Curtman, L. J., Qualitative Chemical Analysis, p. 222, MacMillan Co., 1933.
[15] Psilomelane and cryptomelane are the chief ore minerals in the Appalachian States.

portant manganese mineral. Franklinite $(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$, and two of its alteration minerals, chalcophanite and hetaerolite, are less important minerals. Jacobsite, $(Mn,Mg)O.(Fe,Mn)_2O_3$, and bixbyite, $FeO.MnO_2$, are two other mixed oxides of lesser importance.

Rhodochrosite, $MnCO_3$, is the only important carbonate of manganese.

The silicates of manganese include chiefly rhodonite, $MnSiO_3$, and spessartite, $Mn_3Al_2(SiO_4)_3$, the manganese garnet. Tephroite, Mn_2SiO_4, is much less common.

In addition to the oxides, carbonates, and silicates already mentioned, there are several other important manganese minerals. Columbite-tantalate, $(Fe,Mn)(Nb,Ta)_2O_6$; wolframite, $(Fe,Mn)WO_4$; hübnerite, $MnWO_4$; and alabandite, MnS, all have a wide range of occurrence.

The minerals and mineral groups just named are the most common, though there are many other manganese minerals, some of which attain importance at individual localities.

Iron ores frequently contain manganese. They are known as manganiferous iron ores when they contain 5 to 10 percent manganese and as ferruginous manganese ores when they contain more than 10 and less than 35 percent manganese. The manganese is usually present in the iron ore as thin veinlets of manganese oxide or is disseminated through the mass. Many of the Pennsylvania iron ores, chiefly the Appalachian Valley ores, contain manganese; at some localities the content may average as high as 10 percent.

IDENTIFICATION OF THE MANGANESE OXIDES

Identification of the manganese oxide minerals is very difficult. For the most part, minerals have certain definite chemical and physical properties. Hence, it is possible to examine most minerals megascopically and determine certain fixed diagnostic physical properties. Likewise, a microscopic examination of most minerals reveals diagnostic physical, and sometimes chemical properties. The manganese oxide minerals, however, are more difficult to identify. Physical properties that seem diagnostic for one oxide may in some cases characterize another and this has led to many errors in identification.

The oxides of manganese are all of similar nature. Because of this, and because of the affinity of some of the oxides for each other and for other elements, notably iron, and many minor impurities, there is actually a long series of oxide compounds of manganese. The deviation from one pure oxide form by mixing with another, or several oxides of a different nature is not revealed by a change of physical properties, nor of chemical properties in many cases. Therefore, it is obvious that the application of simple determinative criteria to identify complex oxide minerals, or even simple ones, is not sufficient to be conclusive.

Identification of the manganese oxide minerals of Pennsylvania is based on detailed examination of optical properties of polished surfaces correlated with etching tests and X-ray determinations by the powder diffraction method. The correlated results of all these data proved to be sufficient, in most cases, for accurate identification, un-

less the mixture of manganese oxides is too complex. The methods used and their results follow:

MICROCHEMICAL AND ETCH TESTS

The manganese minerals, especially the oxides, have been carefully studied to determine their optical properties and their reaction to various etch reagents by several investigators. In 1924 Thiel studied the minerals with special regard to their etching reactions; in 1929 Smitheringale did the same for some manganese minerals from Canada and correlated his results with a few X-ray determinations of the same minerals; in 1930 Orcel and Pavlovitch studied many manganese minerals with special regard to their optical properties, including etching reactions; in 1931 Schneiderhöhn and Ramdohr published the results of detailed optical studies of the ore minerals, including the manganese oxides.[16]

These studies have contributed data to the knowledge of the manganese oxides, but their diverse results on supposedly constant minerals are mute testimony to the unsatisfactory state of knowledge concerning them. Smitheringale's correlative work between X-ray determinations and etching reactions was important. Schneiderhöhn and Ramdohr, though they mention X-ray determinations, do not present careful correlations between them and the long descriptions of the optical character of the minerals determined in polished section.

More recent, unpublished researches, by a group of men in the laboratories of the U. S. Geological Survey[17] and some published work[18] indicates that the manganese minerals cannot easily be identified by optical properties and etching reactions, but only definitely by X-ray determination with the powder diffraction method. Heterogeneous manganese oxide minerals are not easily, and often cannot be, identified by X-ray methods.

During this investigation manganese minerals from numerous localities in Pennsylvania were studied to determine their optical properties and their etching reactions. The minerals from both localities which are commercial possibilities were identified by X-ray powder photographs, as were several more homogeneous specimens from other localities. Others were not suitable for X-ray determination. The results of detailed etching tests on 28 minerals are presented in Table 2 and the detailed results of tests on specimens H-1, B.S.-10, W-1, and B.S.-9a are fully described in the text.

Technique of microchemical and etching tests. A microchemical test for manganese was made on all doubtful minerals. The test used was the sensitive qualitative sodium bismuthate test cited by Chamot

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[16] Thiel, G. A., The manganese minerals: Econ. Geol., vol. 19, pp. 107-146, 1924.
Smitheringale, W. V., Notes on etching tests and X-ray examination of some manganese minerals: Econ. Geol., vol. 24, pp. 481-506, 1929.
Orcel, J. et St. Pavlovitch, Les caracteres microscopiques des oxydes de manganese et des manganites naturels: Bull. de la Soc. Francaise de Mineralogie, Tome 54, pp. 108-179, 1931.
Schneiderhöhn, H., und Ramdohr, P., Lehrbuch der erzmikroscopie, 714 pp., vol. 2 Berlin (Borntraeger), 1931.

[17] C. F. Park, Jr., C. Milton, P. Richmond, M. Fleischer.

[18] Fleischer M., and Richmond, W. E., The manganese oxide minerals: a preliminary report: Econ. Geol., vol. 38, No. 4, pp. 269-286, 1943.

and Mason and by Short.[19] A small amount of the mineral was gouged from the surface of the polished section and taken into solution with three drops of 1:1 HCl. The residue, $MnCl.4H_2O$, which is pink and crystalline, collects around the periphery of the drop. The residue is taken into solution, with a drop of 1:7 HNO_3, and to this is added a small amount of sodium bismuthate. The bivalent manganese is oxidized to the permanganate state and the MnO_4 ions color the solution pink or purple. In less than half a minute the solution loses its color and MnO_2 is deposited as a black powder around the periphery and in toward the center. The test is diagnostic for as little as 0.02 percent of $MnCl_2.4H_2O$ in the solvent of 1:7 HNO_3.

The "spot" method of etching was used in this investigation. This is preferable to Schneiderhöhn's method of structural etching, in which the entire surface is immersed in a bath of the etch reagent, for three reasons:

1. Electrolytic effects between two or more different minerals in the section are avoided.
2. The action of the reagent can be observed under the microscope.
3. The entire surface, or its greater part, is not spoiled for further etching.

The procedure followed is essentially that recommended by M. N. Short and L. C. Graton. A fine diameter platinum wire about one inch long, mounted in a glass holder at one end, was used to apply the reagents to the polished surfaces. The end of the wire was made into a loop with a diameter of about 1 millimeter. This small loop was bent at a slight angle to the rest of the wire so that it would lie parallel to the polished surface when the holder and wire were held at an angle. The small loop holds the reagents by surface tension.

The reagent drop is applied to the surface and allowed to remain one minute. Most active reagents react in this time, and longer application might destroy the effect. The action of the reagent can be controlled because the action is observable through the microscope, and it can be stopped at any time. At the end of one minute the surface is carefully washed with water and examined. Then the surface is rubbed vigorously with a chamois and observed again. Finally, the etched spot is scratched by a needle.

Reagents. The reagents used to determine etching reactions were selected from those recommended by Thiel and later used by Smitheringale and Schneiderhöhn and Ramdohr. Those best suited to this study were:

1. Stannous chloride ($SnCl_2$), saturated solution.
2. Ferric chloride ($FeCl_3$), concentrated.
3. Hydrogen peroxide (H_2O_2), 3 percent.
4. Hydrochloric acid (HCl), 3 percent.
5. Potassium carbonate and potassium nitrate ($KCO_3 + KNO_3$) (equal parts of a saturated solution of each).
6. Sulphuric acid (H_2SO_4), concentrated.

[19] Chamot, E. M., and Mason, C. W., Handbook of chemical microscopy, 2 vols. New York, 1931.
Short, M. N., Microscopic determination of the ore minerals: U.S.G.S. Bull. 914, p. 226, 1940.

Etching tests. The complete etching tests for four (4) minerals follow:

Cryptomelane (h-1): Cryptomelane is the chief ore mineral at the Sherman Valley open cut, Bedford County. This specimen was identified as cryptomelane by the X-ray powder method.[20] The results of the etching tests are given below:

$SnCl_2$ (sat.).—Slow positive reaction, etching the surface to a dark brown "matted-crystalline" appearing mass. Rubs to a slightly lighter brown, finely textured figure, grey on the edges. This surface can be scratched.

$FeCl_3$ (conc.).—The yellow color of the solution disappears as the surface is stained a light brown. Cannot be rubbed off or scratched.

H_2O_2 (3%).—Effervesces slowly. Evaporates, leaving a peripheral brown-black residue which cannot be rubbed off but can be scratched.

HCl (1:1).—Light brown stain which can be rubbed off. Slight scratched appearance.

HCl (conc.).—Darker brown stain which rubs to light brown, slightly roughened and scratched surface.

$KCO_3 + KNO_3$.—Negative effect; washes clean.

H_2SO_4 (conc.).—Negative effect; washes clean.

Cryptomelane (B.S.-10): The chief manganese mineral at Reading Banks, Cumberland County, is cryptomelane. It was identified by the X-ray powder method.[21]

The etching tests on this mineral are:

$SnCl_2$ (sat.).—Drop slowly evaporates to a lath-shaped, crystalline figure. Rubs to a grey, very fine-textured surface. This surface cannot be scratched.

$FeCl_3$ (conc.).—Negative effect; washes clean.

H_2O_2 (3%).—Effervesces slowly. Washes to a very slightly darker stain. Rubs to original polished surface.

HCl (1:1).—Fumes from the drop tarnish the surface brown around the periphery. Rubs to a uniform light brown stain. The stain cannot be scratched.

HCl (conc.).—Immediate dark brown tarnish around periphery of drop by the fumes. Rubs to a pitted etch figure.

$KCO_3 + KNO_3$.—Negative effect; washes clean.

H_2SO_4 (conc.).—Surface very slowly darkens under the drop; rubs to a very light brown stained surface which can be scratched.

Pyrolusite (W-1): The chief mineral at the old Wharton Mine in Cumberland County is pyrolusite. This specimen was identified by the X-ray powder method. The etching tests on the mineral are:

$SnCl_2$ (sat.).—Slow positive reaction under drop. Much of drop absorbed in porous surface. Slight iridescent tarnish which rubs to a light grey stain. The stain can be scratched.

$FeCl_3$ (conc.).—After two minutes a slight positive brown stain. Rubs to a faint grey surface which can be scratched.

H_2O_2 (3%).—Effervesces. Washes clean with very slightly darkened surface.

HCl (1:1).—Fumes from the drop stain surface brown around periphery. Rubs to a uniform light brown stain. Cannot be scratched.

HCl (conc.).—Fumes immediately stain dark brown around periphery of drop and along scratches and cracks. Rubs to a uniform dark brown stain in which scratches stand out.

$KCO_3 + KNO_3$.—Negative effect; washes clean.

H_2SO_4 (conc.).—Negative effect; washes clean.

Manganite (B.S.-9a): A minor mineral, occurring as replacement veins in iron oxide ore at Reading Banks, Cumberland County, is

[20] Determination by W. Richmond, U. S. Geol. Survey, 1941.
[21] Determination by W. Richmond, U. S. Geol. Survey.

manganite. This mineral has been identified by its optical properties; no confirmatory X-ray determinations could be made. Results of the etching tests are:

$SnCl_2$ (sat.).—Slow development of needle-like outline under drop; evaporates to aligned prismatic figure. Rubs to a smudged, dark grey stain. Cannot be scratched.

$FeCl_3$ (conc.).—Negative effect; washes clean.

H_2O_2 (3%).—Very slight effervescence. Rubs to a medium grey surface.

HCl (1:1).—Fumes stain surface light brown in 1 mm. aureole around the drop. Rubs to a very light grey stain.

HCl (conc.)—Fumes tarnish dark brown, especially at border of vein and along scratches. Rubs to a very slightly darker grey than 1:1 HCl. Scratches on the surface are accentuated.

$KCO_3 + KNO_3$.—Drop evaporates forming elongate grey crystals pointing in toward center. Rubs nearly clean, but permanent light grey stain.

H_2SO_4 (conc.).—Negative effect; washes clean.

Discussion of results. The etching results of this study agree with many of Smitheringale's results. They are in less accord with Thiel's. Smitheringale's specimens were identified by X-ray determinations. With the exception of specimen B.S.-9a, the four specimens described have been identified by X-ray determination. These minerals, therefore, should have diagnostic etching reactions which would serve to identify other specimens of the same minerals. The data of Table 2, however, show variations in the etching reactions for the two specimens of cryptomelane. These variations are probably indicative of physical changes that are not observable in polished section. Therefore, etching tests, on dense, finely-granular, amorphous minerals, such as the manganese oxides, are not necessarily diagnostic and must be interpreted with caution.

Table 2. Results of Etching Tests

	$SnCl_2$ (sat.)	$FeCl_3$ (conc.)	H_2O_2 (3%)	HCl (1:1)	HCl (conc.)	KCO_3 & KNO_3	H_2SO_4 (conc.)
H-1		Sli					
Cryptomelane	P	P	P	P	P	N	N
H-2a		Sli					
Cryptomelane	P	P	P	P	P	N	N
H-2b							Sli
Cryptomelane (1st generation)	P	P	P	P	P	N	P
							Sli
Cryptomelane (2nd generation)	P	P	P	P	P	N	P
H-3							
Cryptomelane	P	P	P	P	P	N	N
			Str				
Pyrolusite	N	N	P	N	N	N	N
H-4							Sli
Cryptomelane	P	N	P	P	P	N	P
H-5							
Cryptomelane	P	P	P	P	P	N	N
B.S.-1a							
Cryptomelane	P	P	P	P	P	N	N
B.S.-1b							Sli
Cryptomelane	P	N	P	P	P	N	P

P = Positive; N = Negative; Sli = Slightly; Slo = Slowly; Str = Strongly.

Table 2. Results of Etching Tests—Continued

	$SnCl_2$ (sat.)	$FeCl_3$ (conc.)	H_2O_2 (3%)	HCl (1:1)	HCl (conc.)	KCO_3 & KNO_3	H_2SO_4 (conc.)
B.S.-3b							
Cryptomelane	P	P	P	P	P	N	N
B.S.-5a							
Cryptomelane	P	P	P	N	N	N	N
B.S.-5b							
Cryptomelane	P	P	P	P	P	N	N
B.S.-8							Sli
Cryptomelane	P	N	P	P	P	N	P
B.S.-9a	Slo		Slo	Sli	Sli	Sli	
Manganite	P	N	P	P	P	P	N
			Str				
Pyrolusite	P	N	P	P	P	N	N
B.S.-9b							
Cryptomelane	P	P	P	P	P	N	N
B.S.-9c	Slo		Slo		Sli	Sli	
Manganite	P	N	P	N	P	P	N
B.S.-9d		Sli					
Cryptomelane	P	P	P	P	P	N	N
B.S.-10							Sli
Cryptomelane	P	N	P	P	P	N	P
H.F.		Sli					
Cryptomelane	P	P	P	P	P	N	N
P-1	Slo		Str				
Pyrolusite	P	N	P	P	P	N	N
E-1							
Cryptomelane	P	P	P	P	P	N	N
Mc-1			Str				
Pyrolusite	N	N	P	N	N	N	N
Mc-2							
Cryptomelane	P	N	P	P	P	N	N
W-1	Slo	Sli	Str				
Pyrolusite	P	P	P	P	P	N	N
							Sli
Cryptomelane	P	N	P	P	P	N	P
L.B.-1		Sli					Sli
Cryptomelane	P	P	P	P	P	N	P

P = Positive; N = Negative; Sli = Slightly; Slo = Slowly; Str = Strongly.

Optical Data

The optical data of the four specimens, H-1, B.S.-10, W-1, and B.S.-9a are presented in Table 3. These specimens are representative of three of the manganese oxide minerals that occur in Pennsylvania, cryptomelane (the most abundant mineral), pyrolusite, and manganite.

Discussion of properties. The optical properties observed and measured on polished sections include:

Color: The color of reflected light from the polished surfaces of the different manganese minerals varies but slightly, and only from white to shades of grey. Color determinations are extremely subjective and must be used cautiously.

Reflectivity: Reflectivity measurements were qualitative only. The quantitative methods used by Schneiderhöhn, Orcel, Moses, and others,

employing either photometric or photoelectric equipment, were not available.

Hardness: Only "hard" and "soft" minerals are recognized in this study, the distinction being based on whether or not the polished surface of the mineral is scratched by a No. 10 Sharps needle when its point is dragged across it.

Angular rotation of polarization plane: Most of the manganese minerals rotate the plane of polarization. Full extinction is obtained at angles of 3°-5°. These angles are so small that exact measurement of them as a diagnostic test for identification is not feasible.

Color under X-nicols: For those minerals lacking any noticeable anisotropic effect and with extinction in some angular position, the color under X-nicols is recorded as contributive data.

Anisotropic effect: Anisotropic effects were observed and measured with the analyzer slightly turned from the crossed position. Though manganite and pyrolusite are two of a small number of minerals supposed to show four extinctions to a revolution of the stage, none of the manganese minerals in this study showed more than two extinctions, including both manganite and pyrolusite. The polarization colors are recorded for all anisotropic minerals, but owing to factors of light intensity, degree of surface polish, and instrument peculiarities, the finer shades of these colors may vary and should be used cautiously.

Other properties: Faint pleochroism was observed on only a few of the manganese minerals. The number and size of cracks was noted on all polished mineral surfaces. With relatively few exceptions, the manganese minerals are amorphous or approach the amorphous state. Crystalline pyrolusite and manganite occur in such minute form that definite optical orientations could not be measured.

Results of optical examination. The data in Table 3 are of minerals that were identified by X-ray determinations, except B.S.-9a. These observations show that data from optical examination of polished surfaces of manganese minerals are not clearly diagnostic.

Cryptomelane H-1 and B.S.-10 show unmistakable differences which might lead to serious error if identification were based upon optical data alone. These differences are due to physical properties. One of these is evident by comparison of the two minerals in polished section. B.S.-10 is more porous and has a slightly "granular" surface texture, whereas H-1 is dense, fine-grained and smooth. It is suspected that the absorbed water content may also influence the resultant optical properties.

The specimen identified as pyrolusite (W-1) contains a small amount of another manganese oxide mineral shown by X-ray determinations. The optical data may be influenced by the other oxide. No occurrences of crystalline pyrolusite were large enough to be identified by X-ray or to be checked by optical data; therefore, the granular amorphous specimen was used. The color and reflectivity do not check the properties of pyrolusite listed by other investigators, but they all used excellent crystalline material. Obviously, the physical properties have affected the optical properties. Precise meas-

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urements on perfect crystals are important as a check but at the same time misleading because not all occurrences of the minerals are perfectly crystalline. Though the anisotropic effect remains fairly constant, regardless of the physical state of the mineral, the effect apparently is weaker for minerals approaching an amorphous state. The polarization colors are constant.

Specimen B.S.-9a was identified as manganite on the basis of optical properties. All of the manganite minerals examined showed similar optical properties as well as constant etching reactions, but they were all finely crystalline or large-grained.

Table 3. Optical data for Four Manganese Oxide Minerals

Optical properties	(H-1) Cryptomelane	(B.S. 10) Cryptomelane	(W-1) Pyrolusite	(B.S.-9a) Manganite
Color	Yellowish-white	Grey-white	Grey-white	Grey
Reflectivity	High	High & medium	Medium & low	Medium-high
Hardness	Hard	Hard	Soft	Hard
Rotation*	3°	3°-5°	None	About 3°
Color under X-nicols	Deep Lavender	Pale Lavender	Black	.....
Anisotropism	None	None	Faint, 2 extinctions per revolution	Strong, 2 extinctions per revolution
Polarization colors	None	None	Grey-white; Black; dark grey	White; grey; brown; violet; dark grey
Pleochroism	None	None	None	Faint, probably 11 to 010
Cracks	Few	None	.....	.....
X-line character	Amorphous	Amorphous	Granular-amorphous	Clusters of radial prisms in center of concentric banded vein
Remarks	No colloform bands	Partly porous; colloform bands	Porous; some impurities	.....

* Angular rotation of polarization plane.

X-ray Data

The most important manganese minerals from four localities were identified by the X-ray powder diffraction method. These results are given in Table 4, with their interplanar spacings ("d" values) along with those of known pure manganese oxides.[22]

Each of the minerals was ground fine enough to pass 200 mesh, mixed with a special paste, and extruded through a hole less than .01 mm. diameter, thus forming a long, slender "hair" of the mineral. Each was mounted in an ordinary X-ray camera with a radius of 57.3 mm. and exposed to X-rays of iron target radiation[23] for from 2 to 48 hours. The "d" values for each of the lines on the negative

[22] Negatives and "d" values for four pure manganese oxides, courtesy of M. Fleischer, U. S. Geological Survey.

[23] Copper and molybdenum targets also used.

were calculated and referred to determinative tables[24] and compared with those of pure, known manganese oxides for the identification of the mineral.

Discussion of results. The "d' values for eight lines are given in Table 4 for four pure manganese oxide minerals and for six mineral specimens from Pennsylvania. The first five lines are in the order of their intensity.

Specimens H-1, H-2, H-3, and B.S.-10, from Sherman Valley and Reading Banks are obviously the mineral cryptomelane according to the "d" values.

Specimen W-1 from the Wharton Mine is mainly pyrolusite. It is not pure, however. The two most intense lines, 1 and 2, correspond to lines 4 and 1 respectively of pure pyrolusite. Line 3 corresponds to line 6 of cryptomelane and line 4 corresponds to line 5 of cryptomelane. Lines 5, 6 and 8 correspond to lines 6, 7 and 8 of pyrolusite. Line 7 corresponds to line 6 of psilomelane. From the order and intensity of the lines, pyrolusite is clearly the main mineral and cryptomelane is a minor impurity. These data check with the optical study of the polished section, in which two minerals of different properties are definitely recognizable, and one is in much greater abundance.

Specimen Mc-1 from the McCarrick Prospect is an excellent example of misinterpretation of minerals. Until the data from an X-ray powder picture were obtained, optical examination led the writer to think pyrolusite was the main mineral and cryptomelane an associated mineral in this specimen. Actually, cryptomelane is the main mineral but is superficially masked in polished section by a lesser quantity of pyrolusite. The mixture of these two minerals has caused a difference in the position of the most intense lines for each as compared with the corresponding pure mineral, as in W-1. Line 1 corresponds to line 2 of cryptomelane; line 2 corresponds to line 1 of pyrolusite; lines 3, 4, 5, and 8 correspond to lines 6, 5, 4, and 3 of cryptomelane; line 6 probably corresponds to line 8 of psilomelane; and line 7 is line 6 of pyrolusite. The mineral is mainly cryptomelane, associated with smaller amounts of pyrolusite. Optical examination shows that cryptomelane has partly altered to pyrolusite.

As shown by specimens W-1 and Mc-1, mixtures of oxides cause changes in intensity of the lines and elimination of some lines altogether. The interpretation of the lines is not simple, but unless the mixture is very complex, the components can be identified by careful measurements and comparison.

Conclusions

Comparison of the results of X-ray examination with the data from optical examination and etching tests of the seven Pennsylvania manganese minerals indicates that:

1. Exact identification of the manganese oxides should be based on both optical and X-ray data.

[24] National Research Council: Tables on X-ray powder photographs.

2. Identification of the minerals from one locality is possible by optical methods providing at least one, preferably two or three X-ray pictures supplement the identifications.
3. Etching tests alone are not a satisfactory means of identification, but are helpful if supplemented by optical examination and X-ray determination.

Table 4. X-ray Identification of Manganese Oxides

Location	"d" values of 8 lines; first five in order of intensity 1	2	3	4	5	6	7	8	Mineral
Pure Minerals									
Urucum, Brazil	3.10	2.39	2.15	4.89	6.95	1.82	1.56	1.63	Cryptomelane
Platten, Bohemia	3.11	1.62	1.55	2.40	2.11	1.52	2.18	1.38	Pyrolusite
Ilfeld, Germany	3.43	2.27	2.65	1.67	1.70	1.78	1.49	1.63	Manganite
Romaneche, France	3.52	3.14	2.28	2.20	2.16	1.43	2.43	1.84	Psilomelane
Penna. Minerals									
Sherman Valley*	3.10	2.39	2.16	4.89	6.95	1.82	1.56	...	Cryptomelane
Reading Banks†	3.10	2.39	2.15	4.89	6.94	1.82	1.57	1.63	Cryptomelane
Wharton Mine (W-1)	2.41	3.13	1.82	7.39	1.54	2.19	1.42	1.36	Pyrolusite (plus cryptomelane)
McCarrick Prospect (Mc-1)	2.39	3.12	1.82	7.07	4.71	1.89	1.53	2.14	Cryptomelane (plus pyrolusite)

* H-1, H-2, H-3.
† White Rocks B.S.-10.

DESCRIPTION OF THE COMMON MANGANESE MINERALS

Though it is not possible to identify manganese oxide minerals accurately on the basis of megascopic criteria alone, it is necessary to assume that it *is* possible in order to create some common ground for the discussion and description of manganese minerals commonly observed and found in Pennsylvania. This is necessary for both the scientist and layman, for some uniform terminology in any description is essential. The purpose here is to describe carefully the typical and most common manganese minerals, especially those occurring in Pennsylvania, so that the layman will understand the character and nature of each mineral type and more fully appreciate its occurrence and significance. The importance of the manganese ore minerals to the nation has been paramount during two periods of world war. It is entirely possible that many individuals can further the knowledge

of the State's manganese mineral resources by having a knowledge of the minerals and their usual occurrence, and by reporting new manganese mineral localities to the Geological Survey.

The manganese oxide minerals are similar to the iron oxide minerals in appearance and may often be mistaken for them. The simplest distinction between the two groups is by color and streak. Most manganese oxide minerals have a black or blue-black color; the iron oxide minerals are more often brown and red than black. A good diagnostic test to distinguish between the two groups in the field is to scratch the mineral on a white porcelain plate or to powder part of the mineral with a sharp blow from a pointed hammer. The color of the powder on the mineral or the white plate is called the *streak*. The manganese oxide minerals all possess very dark brown or black streaks. The iron oxide, limonite, makes a yellowish-brown streak and hematite makes a reddish-brown streak. Mixtures of iron and manganese oxides make brownish-black streaks.

Pyrolusite. Pyrolusite (MnO_2, generally with a little H_2O) is a soft, opaque gray-black to black crystalline or granular mineral. When distinctly crystalline, it has a metallic luster, but it is generally nonmetallic. It is soft enough so that it may be scratched by the finger nail (hardness 2-2½) and it soils the fingers with a sooty black smudge. Some specimens have a hardness of as much as 6½. The specific gravity is about 4.8 and the streak is black. It contains 63.2 percent of manganese in its pure form. It has been shown[25] that some crystalline pyrolusite is primary but apparently most of it results from the oxidation of manganite with an accompanying loss of water, the material being pseudomorphous after the crystalline structure of manganite and often retaining the radiate structure of manganite.[26] It occurs commonly as a thin coating on other manganese minerals in the Appalachian Valley region. Often it forms reniform coatings and is also massive. More rarely it is columar[27] and sometimes crystallizes in plumose forms. Small amounts of pyrolusite have been found at many of the manganese mineral localities in Pennsylvania.

"Polianite." According to Fleischer and Richmond[28] the name "polianite" should be dropped from nomenclature of the manganese oxides as it is the same as pyrolusite. Former descriptions characterized "polianite" as being harder and lighter in color than pyrolusite.

"Psilomelane type" minerals. In accordance with the suggestion made by Fleischer and Richmond,[29] the writer is using the term "psilomelane type" to refer to all the manganese oxide minerals that have been confused by being called psilomelane, even though specific identification shows them to be another mineral.

"Psilomelane type" minerals are hard, dense, amorphous, and have a black to steel-gray and bluish-gray color. They have a submetallic

[25] Watson, T. L., and Wherry, E. T., Pyrolusite from Virginia: Wash. Acad. Sci. Jour., vol. 8, pp. 550-560, 1918.
[26] Thiel, G. A., The manganese minerals: Econ. Geol., vol. 19, No. 2, p. 120, 1924.
[27] Stose, G. W., and Schrader, F. C., Manganese deposits of East Tennessee: U.S.G.S. Bull. 737, p. 13, 1923.
[28] Fleischer, Michael and Richmond, W. E., The manganese oxide minerals: a preliminary report: Econ. Geol., vol. 38, No. 4, p. 272, 1943.
[29] Fleischer, Michael and Richmond, W. E., op. cit., p. 271, 1943.

luster, a hardness of 5-6 (so that a good knife blade can barely scratch them), and a specific gravity that ranges from about 3.7 to 4.7. Their streak is black or brownish-black. The manganese content ranges between 50 and 57 percent because of the indefinite composition and the presence of varying amounts of minor elements like potassium, barium, and water. These minerals are frequently mammillary, botryoidal or stalactitic, all forms of concentric structure that result from rhythmic accretionary growth. They are also massive, and almost always exhibit excellent conchoidal fracture.

"Psilomelane type" minerals are the most common manganese minerals in Pennsylvania. As typically developed in the Appalachian Valley region of Pennsylvania, they are nodular, mammillary minerals occurring in the yellow residual clays of weathered limestone and dolomite horizons overlying the basal Antietam sandstone. The nodules range in size from a pea to massive boulder-like forms nearly as big as a small desk. They are typically reniform. Often the minerals develop in small grape-like or botryoidal clusters. On a fractured surface every nodule clearly shows the evidence of concentric growth by the addition of thin laminae of the mineral in a more or less uniform manner. Differences in color and density of the different laminae attest to the fact that mineral matter was deposited from solutions that changed in character either because of the source of the solutions from above or the nature of the medium of replacement, which in most cases is the yellow residual clay. Frequently stalactitic and rod-like forms of psilomelane are found in a similar environment. These forms present evidence that the mineral was developed by deposition from downward moving solutions in open cavities. They seem to be more frequent where the residual clay is thicker, indicating a greater thickness of the original limestone and a corresponding greater decrease in volume with more cavities in the residual clay. Where there are fewer cavities in the clay, the condition is reflected by a greater development of nodular and reniform masses of the minerals and fewer stalactitic forms.

"Psilomelane type" minerals are all secondary minerals in Pennsylvania. They are known to form from hausmannite by oxidation[30] and their derivation from other manganese oxides, carbonates, and silicates is likewise established.

The well-known minerals braunite, hausmannite, and pyrolusite have all been miscalled "psilomelane" at one time or another. Because pyrolusite is the only one of these three minerals that has widespread occurrence in Pennsylvania, it might be mistaken in the field and classified as a mineral of the "psilomelane type." Other minerals that are included in "psilomelane type" include hollandite ($Ba\ R_8O_{16}$ (?), R=Mn^{IV} chiefly, also Fe^{III}, Mn^{II}, Co)[31], coronadite ($Pb_8R_{16}O$. (?), R=Mn^{IV} chiefly, also Mn^{II}, Cu, Zn), ramneite ((Ca, Mn^{II}) $Mn_4{}^{IV}\ O_9$·3H O (?)), and lithiophorite ($Li_2(Mn^{II}, Co, Ni)_2$-$Al_8Mn_{16}{}^{IV}\ O_{35}.14H_2O$ (?)). These are less common materials and at this time, only hollandite has been definitely identified as occurring in the State.

[30] Hewett, D. F., and Miser, H. D., Manganese carbonate in the Batesville district, Arkansas: U.S.G.S. Bull. 921-A, p. 16, 1941.

[31] This and the immediately succeeding formulas are after Fleischer, M. and Richmond, W., op. cit., pp. 273-278, 1943.

Two specific minerals comprise about 90 per cent of all occurrences of "psilomelane type" minerals. The most common mineral is called cryptomelane.[32] The other is psilomelane. Cryptomelane ($K\ R_8O_{16}(?)$, $R=Mn^{IV}$ chiefly, also Mn^{II}, Zn, Co) may best be distinguished from psilomelane ($Ba\ R_9O_{18}.2H_2O(?)$, $R=Mn^{IV}$ chiefly, also Mn^{II}, Co) in the field by a simple, qualitative flame test. The mineral should be powdered and introduced into the flame on a platinum (or nichrome) wire. A strong violet potassium flame (use of a Merwin screen or a blue glass recommended) indicates cryptomelane. If the powdered mineral, when moistened with dilute HCl and placed in the flame, shows a persistent yellowish-green barium flame, the mineral psilomelane is indicated.

Accurate identification of the "psilomelane type" minerals is ultimately dependent on X-ray determinations by the powder diffraction method.

Manganite. Manganite ($Mn_2O_3.H_2O$) is a steel-gray to black crystalline or granular mineral with a submetallic to metallic luster. It has a dark reddish-brown or black streak, a specific gravity of 4.2 to 4.4 and a hardness of 4. A knife blade scratches it readily. There is 62.4 percent of contained manganese and 10.3 percent of water. It crystallizes in prisms of the orthorhombic system and as wedge-shaped crystals with deep vertical striations. Also, a common form is "needle ore", and radial bands of long needle-like crystals of manganite are commonly associated with "psilomelane type" minerals in residual clays of the Appalachian manganese ores. Some nodules from Pennsylvania deposits show an alternating relation of bands of "psilomelane type" minerals and radiating manganite needles. Manganite occurs as an oxidation product of carbonates and silicates, but is found only sparingly in residual deposits.

Hausmannite. Hausmannite ($MnO.Mn_2O_3$ or Mn_3O_4) is a steel-grey, granular and partly crystalline mineral with a submetallic luster. It has a chestnut-brown streak, a specific gravity of 4.8, and a hardness of 5.5. Its brittle character and a perfect basal cleavage help distinguish it from the other oxides of manganese. When pure, it contains 72 percent of manganese. Pure, isolated specimens of hausmannite are rare, however, especially in the Appalachian region, where it is mixed with other manganese minerals. Dana reported a specimen from Lebanon County.

Braunite. Braunite ($3Mn_2O_3.MnSiO_2$) is a black to steel-gray mineral with a submetallic luster, possessing a specific gravity of 4.8, a brownish-black streak, and a hardness of 6. It is often massive with a granular texture, but it is also crystalline, exhibiting well-developed tetragonal crystals. It contains from 63 to 66 percent of manganese. Braunite is commonly mixed with "psilomelane type" minerals and is difficult to distinguish from them if it is not crystalline. It is also difficult to distinguish from crystalline hausmannite, which resembles it in many particulars, but a chemical analysis readily reveals the silica content of braunite, which is a fundamental chemical difference. In addition to its mixed association with the "psilomelane type"

[32] Richmond, W. E. and Fleischer, Michael, Cryptomelane, a new name for the commonest of the "psilomelane" minerals: Am. Mineral., 27, pp. 607-610, 1942.

minerals, it occurs as crystals lining nodules of psilomelane, as small aggregates of octahedral crystals, and in common association with primary manganese silicates, like garnet, spessartite, rhodonite and tephroite, as well as with rhodochrosite, the primary manganese carbonate. Though braunite has not been absolutely identified in Pennsylvania, it has been reported from Edgehill, Montgomery County.[33]

Wad. Wad is a soft, dark brownish-black to bluish-black aggregate of manganese oxides containing variable amounts of water, alumina, silica, and iron oxides. It is always very light, having a specific gravity of about 3. It soils the fingers with a sooty black smudge and is usually very soft, though some forms of wad approach a hardness of 6. Manganese ranges from 20 to 40 per cent. However, black manganiferous clay, which often is associated with wad, is frequently called by that name, and its manganese content may be as little as 5 percent. Wad is fairly common in Pennsylvania, and is very frequently found associated with the clay and other manganese oxides in the many old iron ore pits of the Appalachian Valley.

Bog manganese. Bog manganese consists mainly of a soft brownish-black to black manganese oxide with a very large water content. There are no known true manganese bogs in Pennsylvania, but there are abundant iron oxide bogs that contain from one to eight percent of manganese. The bogs are usually quite small, rarely being more than 3 or 4 feet deep or more than 25 feet in diameter. When the bog is young, it is very soft and swamp-like; when it is old, it may easily be told by the springy character of the ground and the deep red to black color of the soil.

Rhodochrosite. Rhodochrosite ($MnCO_3$) is a vitreous, pink mineral that is generally massive, encrusting or crystalline. It has a specific gravity of about 3.5, a white streak, and a hardness of 4. A good rhombohedral cleavage and a translucent character in thin pieces is distinctive. The mineral contains 48 percent of manganese. It occurs at Cornwall as a gangue mineral in the magnetite ore body. There are also minor occurrences of the mineral in the southeastern part of Pennsylvania. At no place is it in sufficient abundance to be an ore mineral of manganese.

Rhodonite. Rhodonite ($MnSiO_3$) is the most important manganese silicate mineral. It is a vitreous pink to brownish-red mineral, having a specific gravity of 3.5, a hardness of 6, and commonly occurs in tabular-crystalline or massive form. It is associated with other manganese silicate minerals, is present at Cornwall, and has been found at many places in the southeastern part of the State. Pure rhodonite contains about 42 percent of manganese. It sometimes alters to form the manganese oxide minerals psilomelane, cryptomelane, and braunite.

Spessartite. Spessartite ($Mn_3Al_2(SiO_4)_3$) is the manganese garnet. It is a deep red, crystalline mineral, with a specific gravity of 3.2 and a hardness of 7. Commonly it occurs as dodecahedral crystals in the gneiss and schist rocks of the southeastern part of the State. Spes-

[33] Genth, F. A., Mineralogy of Pennsylvania: Penna. 2nd. Geol. Survey, vol. B, p. 45, 1875.

sartite contains 33 percent of manganese. It alters through weathering processes which may lead directly to the formation of the common manganese oxide minerals, psilomelane, cryptomelane, and wad.

Tephroite. Tephroite (Mn_2SiO_4) is the manganese olivine. It is a flesh-red to ash-gray mineral with a specific gravity of 4.1 and a hardness of more than 6. Tephroite contains 37 percent of manganese and, like spessarite, occurs in small quantities throughout the gneissic rocks of the Piedmont. It yields the common manganese oxide minerals of weathering.

Mixed manganese-iron ores. The manganese oxide minerals, chiefly cryptomelane, psilomelane, pyrolusite, and manganite, comprise the ore minerals of manganese. Many of their occurrences in Pennsylvania, especially in the Appalachian Valley region, are in intimate association with iron oxide minerals, the chief one being limonite.[34] The percentage of manganese present in the mixed manganese-iron ores is extremely variable. It ranges from pure limonitic ore and iron ores containing one percent of manganese to ores containing more than 45 percent of manganese.

The solubility of manganese and iron is very similar for all conditions. This fundamental chemical similarity accounts for the strong affinity of manganese for iron and vice versa, and for the intimate relation of the manganese and iron oxide minerals in their natural occurrence. Cryptomelane and limonite most frequently occur together. They are generally recognizable as two distinct minerals that are mixed together. Frequently thin veins of the steel-gray, hard cryptomelane cut across massive brown, softer limonite; also, limonite veinlets may penetrate massive and nodular cryptomelane; sometimes there are nearly equal quantities of the two minerals. Though it is often easy to distinguish between the two minerals in their mixed occurrence, sometimes the presence of either manganese or iron would not normally be expected because the one is in such fine mechanical mixture with the other, or perhaps in chemical combination with the other, as to defy recognition without microscopic study. More than 10 percent of either manganese or iron may be present in such manner as to escape megascopic detection. At nearly all the manganese localities in Pennsylvania, however, where manganese and iron oxide minerals are in intimate association, the different minerals can be distinguished megascopically.

[34] Limonite is used throughout this report as a field term for unidentified iron oxides that are usually the mineral goethite ($HFeO_2$).

TYPES OF DEPOSITS

FACTORS INFLUENCING OCCURRENCE

Three fundamental factors are largely responsible for determining the place of occurrence of manganese mineral deposits and, in a lesser manner, the nature of the deposits themselves. The factors are stratigraphic, structural, and physiographic.

Stratigraphy. The importance of stratigraphy to the occurrence of mineral deposits is an evident one in many cases. Frequently, the resistant and impervious nature of a formation which underlies a more pervious and less resistant formation is the decisive factor in causing the precipitation from solution of mineral matter and the accumulation of that mineral matter over a widespread area. This factor has influenced the accumulation of manganese at the base of the Cambrian Tomstown dolomite overlying the Antietam sandstone all along the Great Valley from Northampton County in the northeast to Franklin County in the southern part of the State; it has influenced the accumulation of manganese at the base of the Mississippian Mauch Chunk shale overlying the Pocono sandstone in Bedford and Fulton counties; it has influenced the accumulation of manganese-bearing bogs on the Pocono sandstone in the northern and northwestern tier of counties.

Though of not such obvious importance, another way in which the nature of the stratigraphy has been important to the accumulation of manganese is in the original manganese content of the rocks. All the deposits in the State are of secondary origin and represent accumulation through the action of solutions dissolving original manganese content from neighboring strata. Unfortunately, in all cases, the strata that contained the original manganese have been eroded away or so completely changed by weathering that the original character of the manganese content cannot be determined; therefore, it is not possible to do more than hypothesize about the original source of the manganese, nor is it possible to know the importance that eroded strata may have had in the accumulation of the manganese minerals we see today.

Structure. The physical position of the rocks, or the structure, is significant in the accumulation and formation of all secondary minerals. The structural attitude of the rocks may be favorable to the rapid accumulation and complete preservation of secondary mineral deposits or it may be very unfavorable. Several general catagories will serve to illustrate the importanee of structure to the genesis of secondary deposits. (See figure 2.)

Horizontal and gently dipping sedimentary beds will cause ore-bearing solutions to move slowly down dip or through the strata. Thin concentrations of ore may then accumulate along the dip in some favorable bed. The occurrence of ore in Sherman Valley, Bedford County, is essentially in one horizon of shale which dips uniformly 15-20 degrees northwest. Under conditions of horizontal structure, such as exist in the plateau land underlain by Pocono sandstone in northeastern Pennsylvania, the mineral-bearing solutions may com-

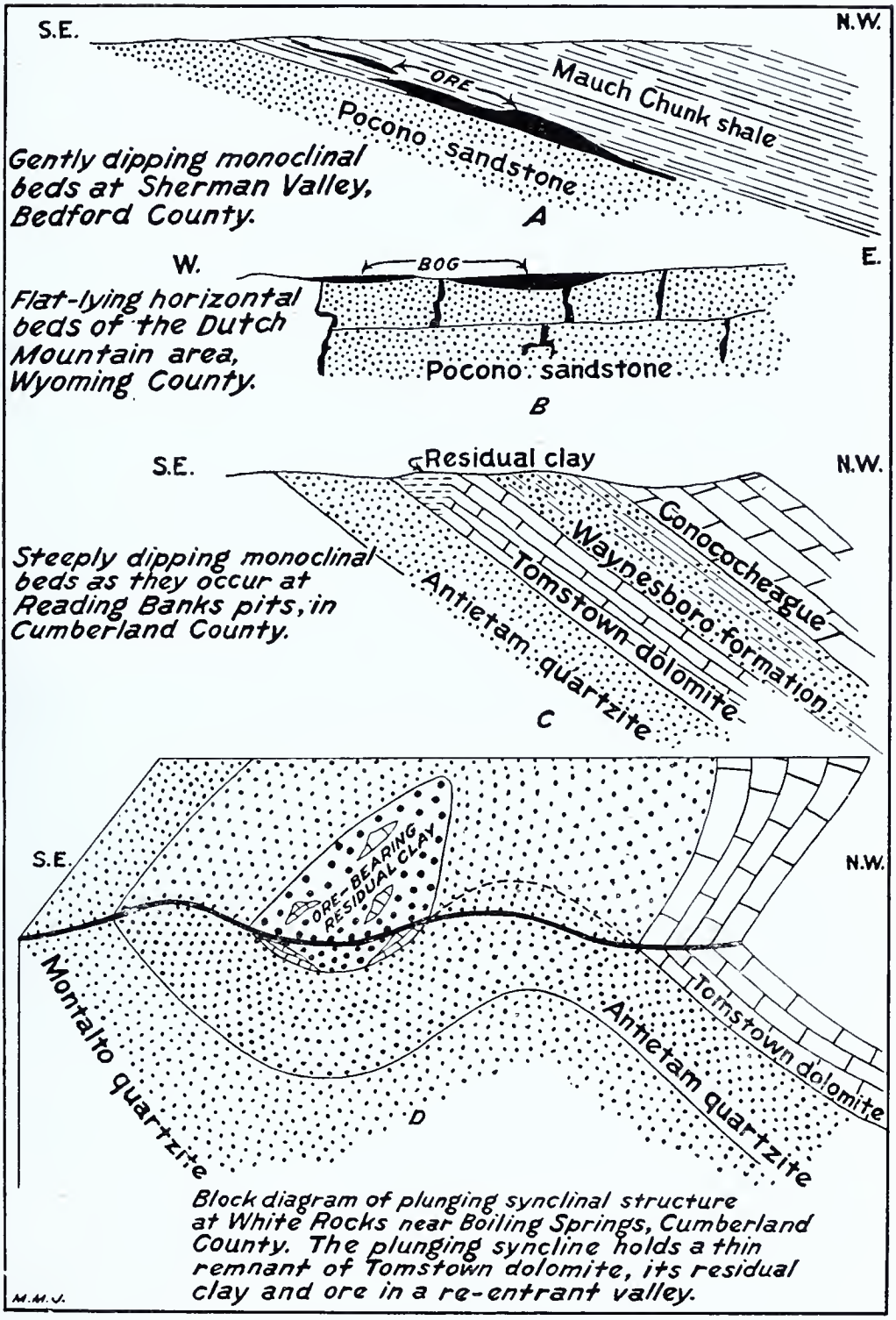

Figure 2. Sketches showing the influence of structure on manganese mineral occurrences.

monly be "ponded" and caused to disseminate very slowly through the rock "pores" and along joint and fracture planes. This condition must have existed in the Dutch Mountain area of Wyoming and Sullivan Counties where manganese oxide occurs as a ubiquitous thin coating through the rocks.

Less favorable structural conditions than those of flat and gently-dipping beds are those created by steeply-dipping monoclinal structures. Under such conditions it is normal to expect that mineral-bearing solutions would be carried away and seldom be concentrated. This is not always true, however, and small deposits of manganese oxide have been worked in clay pockets residual from the Shady dolomite overlying the steeply dipping Erwin quartzite in Virginia and Tennessee.[35] Similar conditions exist at many places in the Cambro-Ordovician beds along the Great Valley in Pennsylvania.

Folded rocks frequently create favorable conditions for the accumulation of mineral matter. The synclinal areas of folds serve as natural catchment basins into which mineral-bearing solutions migrate. Combined with a favorable stratigraphic relationship, such as a clay or limestone overlying a hard, resistant quartzite, such an area is favorable for prospecting. Conditions like this exist near the old Reading Banks ore pits southeast of Boiling Springs in Cumberland County where a prominent synclinal reentrant of Antietam quartzite, overlain by the weathered Tomstown dolomite, cuts into the flank of the pre-Cambrian South Mountain uplift.[36] Stose has described similar conditions in the Southern Appalachians.[37]

Most favorable of all structural conditions, especially when combined with favorable stratigraphic relations, is that of a basin or a plunging syncline. Mineral-bearing solutions descending into such a structural depression will concentrate there and may deposit a large and rich accumulation of mineral matter such as that at the widely known Crimora Mine, near Basic, Virginia, the largest producing manganese mine in the Appalachian States.

The foregoing structural relations account for the physical attitude of most rocks and give a picture of the general categories which can exist. Naturally the structural conditions vary and at any one place are some variation of the general conditions outlined. The most favorable structural conditions are at once those that will cause the greatest concentration of mineral-bearing solutions and those that cause slow downward migration of the solutions, thus allowing freer deposition of mineral matter.

Physiography. The importance that physiographic conditions can play in the concentration of mineral matter has been shown by Stose and Schrader.[38] Many of the manganese mineral deposits in the Appalachians are concentrated at definite levels, on the top of or beneath old stream terraces and along mountain benches, which represent old erosion surfaces. The so-called Harrisburg peneplain, a fairly well defined Tertiary erosion surface, which can be traced through most of the Great Valley in Pennsylvania, is about at the

[35] Stose, G. W., and Schrader, F. C., op. cit., p. 26.
[36] Foose, R. M., Iron-manganese ore deposit at White Rocks, Cumberland County: Penna. Geol. Survey Bull. M26, 1945.
[37] Stose, G. W. and Schrader, F. C., op. cit.
[38] Stose, G. W., and Schrader, F. C., op. cit. pp. 21, 22.

level of many of the old mountain iron ore pits which stretch the length of the Valley. Many of them contain an appreciable percent of manganese. These erosion surfaces are significant because they represent levels to which the land was lowered, involving the removal of many hundreds, and probably thousands, of feet of overlying rocks. It is likely that some of the removed rocks were the chief source rocks of the manganese minerals. The long period of erosion culminating in crude peneplanation was the time of secondary concentration of the manganese minerals. Manganese oxide minerals were deposited from descending mineral-bearing solutions at the base of the deeply weathered zone in many parts of the Appalachians.

Just how important the physiographic factor has been to the accumulation of manganese minerals in Pennsylvania the writer is not fully prepared to say. Much more detailed physiographic work should be done. However, there is a vague relation, as pointed out, between the Tertiary erosion level, at about an elevation of 550 to 600 feet, and the occurrence of secondary manganese mineral concentrations in the Great Valley. In addition, the flat table land area capped by Pocono sandstone in northeastern Pennsylvania, a lowered remnant of a once more extensive erosion surface, is the locus for widely disseminated manganese oxide minerals. On the other hand, many of the manganese mineral localities of the State bear no relation whatever to former erosion surfaces.

SEDIMENTARY DEPOSITS

Deposits of manganese minerals of sedimentary origin in Pennsylvania are insignificant and few in number. In this report sedimentary deposits include stream gravels and sand. These are all of Recent origin. There are no other sedimentary deposits with more than the most scattered concentration of manganese minerals in them. Old stream terraces which might contain manganese minerals, like those in Tennessee,[39] have never been found.

Many streams in the plateau country of northeastern and northwestern Pennsylvania near the bog ore deposits carry considerable manganese in solution. Some of the streams are literally black from the reflection of sand, pebbles, and cobbles that are heavily coated with manganese oxide. Some of the plateau streams 10 feet wide have a continuous black color for a distance of more than 3 miles. The accumulation of manganese oxide takes place when the waters are aerated in crossing riffles and shallows and their manganese carbonate or bicarbonate is oxidized. The less soluble oxide is precipitated. The amount of manganese oxide deposited at any one spot is very small. No important concentrations of this type are known anywhere in the State. Possibly accumulation and concentration may continue so that in future geologic time deposits of real value may exist in stream terraces or in deltaic masses.

A deposit of gravel is tightly cemented by black manganese oxide along Roaring Run in Fulton County where it bends eastward to flow through the gap in Sideling Hill at the village of New Grenada. The 6-inch northward dipping gravel bed of Recent age is overlain by a foot of poorly cemented sand barren of manganese, and under-

[39] Stose, G. W., and Schrader, F. C., op. cit., pp. 47-49.

lain by plastic clay one foot thick (fig. 3). It has no commercial value; thick deposits of this type might.

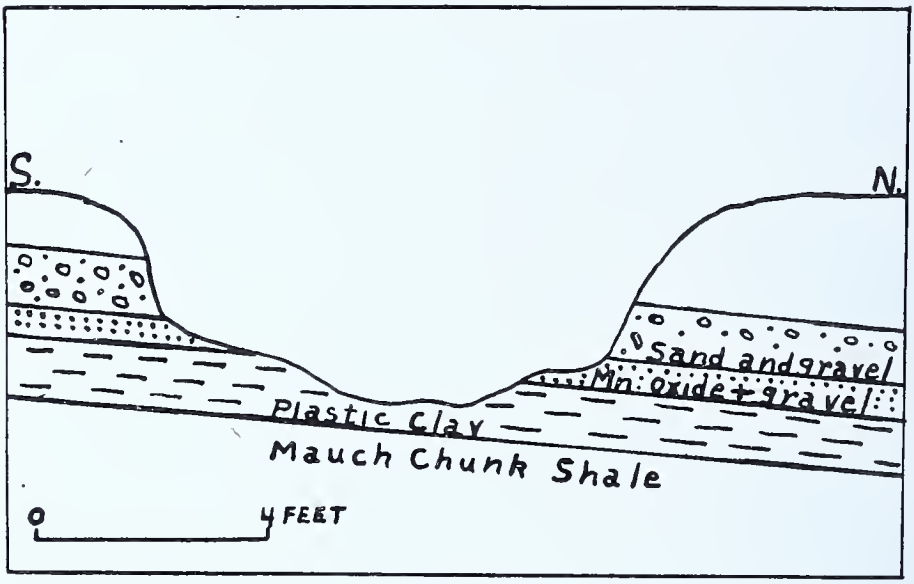

Figure 3. Manganese oxide in gravel bed, Bedford County.

The source of the manganese for this deposit is evidently the ore-bearing basal beds of the Mauch Chunk red shale or the uppermost Pocono sandstone, both of which the stream erodes. Because surface waters do not carry much manganese in solution for long distances, such deposits indicate a close source of manganese minerals, probably a nearby occurence of some other type.

SUPERGENE DEPOSITS

Nearly all the deposits of manganese minerals in Pennsylvania are of supergene origin. Without exception the supergene deposits consist of manganese oxides that have been precipitated from descending ground waters carrying dissolved manganese. Every known deposit of manganese oxide in Pennsylvania which consists of more than a few specimens is associated with varying quantities of iron oxide. The manganese and iron oxides have been derived from the weathering of overlying sedimentary rocks and have accumulated as replacements and associated fracture fillings in lower beds.

In Pennsylvania there are numerous horizons at which the oxide replacement deposits occur. Several of them are characterized by concentrations of manganese oxides, and are, therefore, more important than the others. It is reasonable to expect that new discoveries will be chiefly at these horizons. Table 5 lists the horizons at which supergene manganese minerals have been found in Pennsylvania, arranged in stratigraphic sequence and the number of known deposits at each.

The table shows several interesting associations. Manganese minerals are limited to the Paleozoic and pre-Cambrian rocks. This, of course, ignores the ubiquitous occurrence of thin films and traces

of manganese oxide which have been seen in almost every geologic formation of Pennsylvania. In the Paleozoic sequence there are two horizons which are most important: The Cambrian system as represented by the Antietam quartzite and the Tomstown dolomite of the South Mountain and Great Valley area of southern and southeastern Pennsylvania, and the Gatesburg dolomite of central Pennsylvania; in the Mississippian rocks the most important beds are the Pocono sandstone and Mauch Chunk shale of central and south-central Pennsylvania. The Cambro-Ordovician oxide ore horizons are recognized all along the Great Valley from Pennsylvannia to Georgia and Alabama, but the Mississippian horizon has not had any prior recognition as a possible important horizon for manganese oxide deposits in other Appalachian States.

The factors influencing the occurrence of manganese deposits, previously discussed, have been important in the concentration and accumulation of manganese oxide ores at the above horizons. In addition, the persistent association of specific formations and oxide ore indicates a greater than usual abundance of sedimentary manganese in nearby beds which has been taken into solution by meteoric waters, redeposited, and concentrated. Another association is the presence of manganese oxide minerals in red beds. The Mauch Chunk shale and the Catskill sandstone and shale are red beds. This association will be treated further later on.

Descriptions of the supergene deposits follow in the order of stratigraphic sequence.

Table 5. Geologic Horizons of Supergene Manganese Oxide Minerals in Pennsylvania

Associated rocks	Geologic age of associated rocks	Number of occurrences
Gneiss	Pre-Cambrian	7
Antietam sandstone	Cambrian	3
Tomstown dolomite*	Cambrian	13
Gatesburg dolomite*	Cambrian	3
Ordovician limestone	Ordovician	10
Oriskany sandstone	Devonian	2
Chemung sandstone	Devonian	1
Catskill sandstone and shale	Devonian	3
Pocono sandstone	Mississippian	3
Bogs	Mississippian	21
Mauch Chunk shale*	Mississippian	3
Underclay	Pennsylvanian	2

* Best commercial possibilities.

Oxide ore in gneiss

The Baltimore gneiss and other similar gneissic rocks underlie parts of Lancaster, Chester, Delaware, Philadelphia, Montgomery, and Bucks Counties in southeastern Pennsylvania, forming an elongate and discontinuous belt which trends northeast by east. The gneiss is a medium to coarse-grained crystalline rock comprised mainly of quartz, feldspar, hornblende, and mica, but locally containing a considerable percentage of spessartite, the manganese-aluminum garnet, and some tephroite and piedmontite, the manganese olivine

and manganese epidote. The gneissic rocks weather readily to a soft mantle that frequently retains the gneissic texture. The spessartite and other manganese minerals break down readily and the manganese is probably carried in solution as the carbonate or bicarbonate by meteoric waters.

In the gneiss and adjoining areas small concentrations of soft, black manganese oxides may be expected along fractures in the rock or in swampy, lowland areas where meteoric waters can collect and stagnate. The writer has observed several such occurrences. In no case did the oxide amount to more than a small accumulation of soft wad. There is a possibility that small amounts of pyrolusite and "psilomelane type" minerals may be found in similar places. It is unlikely that any occurrence is of more than mineralogic interest.

Oxide ore in Antietam quartzite

Manganese oxides in the form of stringers, bands and locally massive "psilomelane type" minerals occur in the top of the Antietam quartzite at many places along the flanks of the Great Valley. The occurrence of manganese minerals in the Antietam quartzite is nearly always closely associated with accumulations of the same minerals in the overlying Tomstown dolomite; the oxide ore in the base of the Tomstown dolomite is the logical source of most of the manganese minerals in the top of the Antietam.

The ore occurs both as a replacement of brecciated quartzite and sandstone and as the matrix between the fragments (pl. 10). It is usually associated with earlier deposited limonite which it likewise replaces. The development of colloform banding is the striking textural feature; the bands reflect the nature of movement of the ore-bearing meteoric waters into open spaces and around fragments of brecciated quartzite and limonite. Rarely, the brecciated Antietam and "psilomelane type" ore are associated with fragments of soft, yellow clay, evidently part of the weathered residuum of the overlying Tomstown dolomite beds which was carried down into the upper fractured part of the underlying quartzite. This type of ore occurs at the old Reading Banks pit, two miles southeast of Boiling Springs in Cumberland County. Some of it probably was mined along with the overlying limonite-bearing clays when the property was operated as an iron mine by the Philadelphia and Reading Coal and Iron Co. during the latter part of the 19th century.

Though the manganese and iron oxides mainly occupy only the uppermost parts of the Antietam quartzite, at several localities there is significant replacement of sandstone well below the top. At the McCarrick prospect, one mile southwest of Mt. Holly Springs and five miles west of the Reading Banks pit, along the north flank of South Mountain, pyrolusite and "psilomelane type" ore have locally completely replaced the sandstone and at other places have left only small, rounded fragments of white sandstone which are frequently oriented in thin, subparallel lines showing the direction of movement of the ore-bearing solutions. Larger fragments of sandstone sometimes show the original bedding (fig. 4), but the position of the bedding has been changed by reorientation of the fragments parallel to the flow of the solutions.

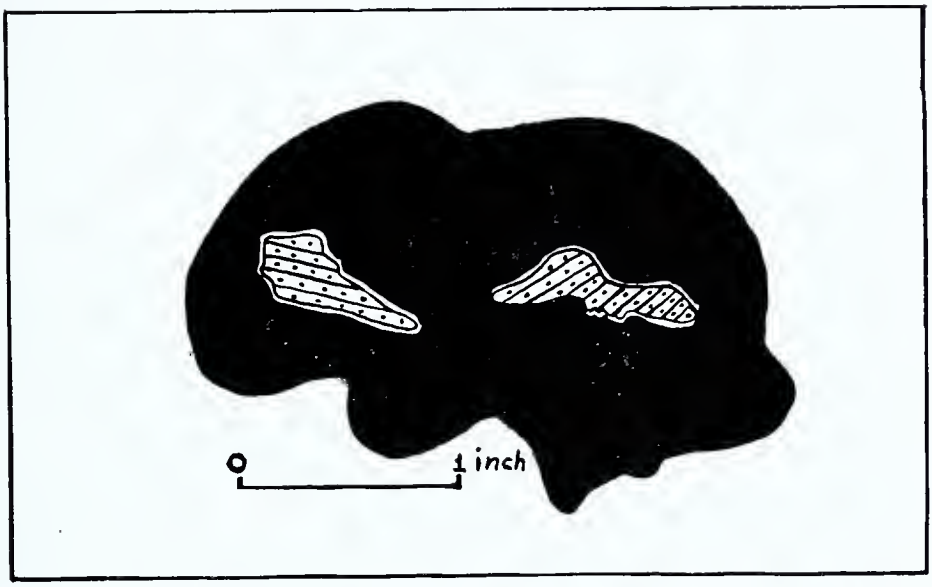

Figure 4. Fragments of Antietam sandstone showing original bedding in mass of replacing manganese oxide.

The McCarrick prospect seems to be well below the top of the Antietam quartzite and out of the zone of greatest brecciation, though it is not possible to measure exactly how far it lies below the Tomstown dolomite.

Replacement of individual quartz grains shows a preference for strained grains exhibiting undulatory extinction; manganese oxide commonly retains the granular texture of the original sandstone.

About 65 years ago, there was some production of mixed limonite-"psilomelane type" ore from the McCarrick property and some high grade ore from the Wharton Mine, two miles southwest of the McCarrick prospect. It may be significant that these better, more concentrated, less siliceous manganese oxides seem to occur at some distance below the top of the Antietam sandstone rather than at the top.

Associated with the limonite, "psilomelane-type", and pyrolusite ore in the Antietam sandstone and quartzite are varying quantities of soft, black manganese oxide, best called wad, resulting from the weathering of the other manganese ores.

Oxide ore in Tomstown dolomite

The most prominent horizon at which manganese minerals occur in Pennsylvania is the base of the Cambrian Tomstown dolomite. Throughout the extent of the Great Valley where the Tomstown formation underlies the flanks of South Mountain and the Reading Hills, manganese and iron oxides occur at many places.

The Tomstown formation does not often crop out; it is usually covered with a heavy mantle of soil and clay, the product of erosion and rock weathering. Though exposures are few and poor, especially in the southwestern part of its extent, the formation is a massive limestone toward the northeast and a coarse, gray dolomite toward

the southwest. Thick, compact beds of dolomite are separated by thin-bedded argillaceous layers and white, sericitic slaty shales. The shaly layers increase toward the base. The formation is estimated to be about 800 feet thick along the flanks of South Mountain in Cumberland County.[40] The abundance of shaly beds near the base indicates a transitional relationship between the more clastic Antietam sandstone below and the purer, chemically precipitated Ordovician limestones above.

Because the formation is relatively impure, residual clays in the Tomstown horizon are unusually well developed. At the base of the formation where it lies in contact with the Antietam sandstone, the clays are commonly thick; they retain traces of the original bedding, though the bedding is completely slumped due to volume shrinkage. The basal clays are rarely free of some superficial mineralization.

The ore occurs in three ways:

1. As fairly solid mixed manganese-iron oxide ore with a slumped bedded character, containing thin interbeds of white and yellow clay, situated at the base of the formation in contact with the Antietam sandstone.
2. As nodules of "psilomelane-type" minerals and limonite in residual yellow clay not far above the base of the formation.
3. As thin beds and stringers of "psilomelane-type" minerals and limonite in tan and yellow clay higher in the formation (probably 200 to 400 feet above the base). Much of the clay is black with disseminated fine, soft, structureless manganese oxide. This wad-like material is non-recoverable.

The physical forms of both the limonite and "psilomelane-type" minerals are extremely varied. In addition to the typical kidney-shaped ore (pl. 10) of the nodular zone, much of the oxide assumes botryoidal, mammillary, stalactitic, and needle-like shapes. The form is partly, if not entirely, dependent upon the local conditions controlling deposition. There seems to be a close relationship between the thickness of the residual clay and the resulting shapes. Where the clay is thick and there has naturally been a larger amount of material removed, volume shrinkage is greater and more open spaces result; in the cavities stalactitic forms of the oxides develop. Where there has been less volume shrinkage and the clay has remained relatively compact, typical reniform growths develop. Subsequent slumping and compaction have closed all the open spaces and disturbed the original position of some of the ore.

With the exception of those iron and manganese oxides deposited in cavities, the ore is a replacement of the residual tan, yellow, and white clays. Although it has been suggested that the oxides may have replaced some of the primary shaly beds of the Tomstown formation prior to its decay and the development of the residual clay, careful field and microscopic studies indicate that the greater part, and probably all, of the supergene mineralization was subsequent to the development of the residual clay. Figure 5 shows manganese oxide replacing and completely enclosing residual clay (pl. 11A). The

[40] Stose estimates the thickness to be 1000 feet near its type locality at Tomstown in neighboring Franklin County.

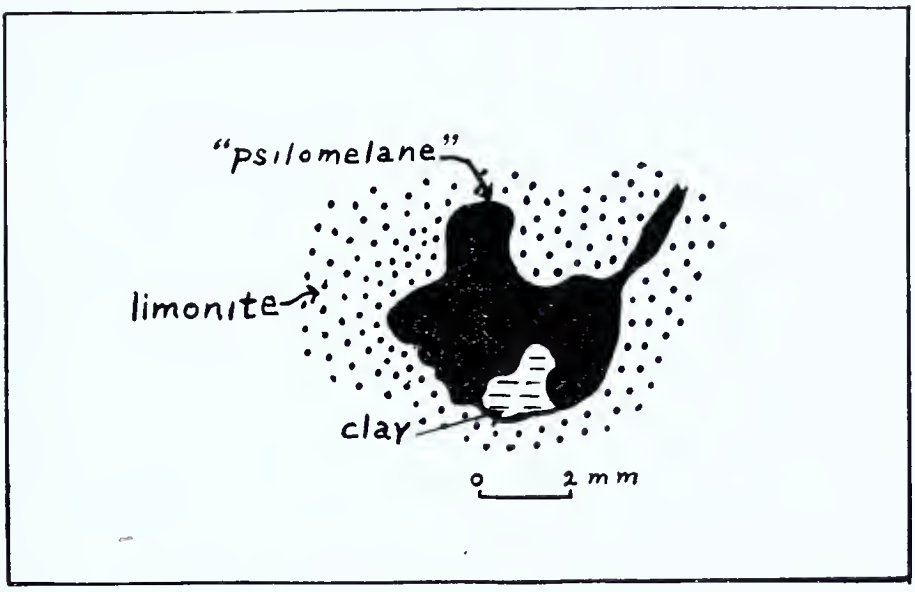

Figure 5. Manganese oxide replacing residual clay.

nature of the replacement is aptly indicated by the excellent colloform texture typical of much of the ore. This is well shown in polished sections (pls. 15, 16). Colloform banding results from rhythmic accretionary growth in a gel-like state,[41] by precipitation from solution in a colloidal medium. The resultant forms are concentric and may be radial or some other shape controlled by unreplaceable components, such as the quartz grains in the residual clay. It is evident that the oxides, carried in downward-moving solutions, replaced the clay in this rhythmic, accretionary manner. Much of the massive ore, though obviously a replacement, shows no colloform texture.

Nature of the clay. The residual clay is earthy, moderately arenaceous, yellow-white. Microscopic examination shows that rounded quartz grains averaging .02 mm. in diameter comprise between 10 and 20 percent of the whole. The remainder of the clay appears as structureless yellow and white alteration products from sericite, carbonate, and possibly some feldspar. All of the constituents of the clay, except the quartz grains, were subject to replacement by the supergene oxides.

Source of the ore. There is insufficient evidence to determine the source of the manganese and iron oxides. Stose[42] believes that similar deposits in East Tennessee had their source in the basal beds of the Shady dolomite, the correlative formation of the Tomstown dolomite. He postulates a soluble form of manganese which was dissolved at the same time the limestone was dissolved by circulating waters and redeposited through replacement action in lower adjoining residual clays. Similar ideas have been held for the Appalachian Valley ores in Virginia. There are not enough places where the Tomstown formation can be investigated with sufficient detail to determine what its

[41] Leisegang, R. E., Geologische diffusionen; Review by A. Knopf, Econ. Geol., vol. 8, p. 803, 1913.
[42] Stose, G. W., and Schrader, F. C., op. cit., p. 26.

primary manganese content may be. At all places where the manganese ores occur, the formation is entirely changed to the embodying residual clay and the overlying beds have been truncated and removed by erosion, thus eliminating the possibility of studying these most pertinent beds in a region of significant oxide formation. Since the great thicknesses of relatively pure Ordovician limestones[43] which normally overlie the Tomstown formation give little evidence of a primary manganese content, it is more likely that the manganese of the Tomstown ores was derived from the relatively impure and rather transitional semi-clastic beds of the Tomstown formation itself.

Grade of the ore. Though the grade of ore varies with local conditions, certain generalizations may be made. The nodular ore usually consists of manganese oxide ("psilomelane-type") and iron oxide (limonite), with very little mixing of the two in individual nodules. This is the best grade of ore. The manganese oxide nodules have an average manganese content which ranges from 40 to 55 percent. The mineral is nearly always cryptomelane. Selective mining for the manganese nodules alone is the simplest way to recover a good grade of ore from the residual clays of the Tomstown formation.

Apparently there is no vertical zoning of the manganese oxide and the iron oxide nodules though field conditions are unfavorable for ascertaining such zoning. Because of post-mineralization slumping of the clay and, in some places, gravity migration of the clay and ore down steep dip slopes, the cryptomelane and limonite nodules are indiscriminately mixed. An original vertical zoning with the greater concentration of cryptomelane nodules than of limonite nodules at a lower level, such as is found at some of the mines and propects in the same horizon in Virginia, may have existed in Pennsylvania, and may still be undisturbed where the structural dips are not too steep. This possibility should be borne in mind. If abundant limonite nodules are discovered on a new and undeveloped tract of land, manganese oxide nodules may be concentrated at a lower level. The vertical zonal relationship is due to the greater solubility of manganese, especially in the form of the carbonate or bicarbonate.

The massive ore and the ore which occurs as stringers and thin beds in clay is mixed ore. The average manganese content is variable, increasing with depth as a general rule. Bands of good, pure manganese oxide alternate with bands of limonite in some places, but the two oxides are more often so thoroughly intermixed that separation is physically impractical. The content of iron ranges from 15 to 50 percent, the manganese content from 5 to 40 percent. Selective mining in some cases, and possibly selective metallurgy, may be able to produce a high-grade product.

Manganese deposits in the base of the Tomstown formation occur at many places along the north flank of South Mountain in Cumberland County. The structural attitude of the beds is important. Concentration of the ore has been largely controlled by small synclinal folds that have enclosed the Tomstown formation with its residual clay in reentrant coves floored by hard, resistant Antietam sandstone (fig. 2). The structural coves also possess topographic expression;

[43] Two to four thousand feet of Beekmantown, Stones River, and Chambersburg limestones.

this is well shown near Mt. Holly Springs and Boiling Springs (Carlisle sheet) in Cumberland County. Several deposits in Franklin County bear the same general relation to South Mountain and to the structure of the beds. Manganese deposits are also known in Northampton, Lehigh, and Berks Counties along the north flank of the Reading Hills where similar conditions prevail.

Oxide ore in Gatesburg dolomite

The Gatesburg dolomite, of late Cambrian age, underlies an elongate area including parts of Bedford, Blair, Huntingdon, and Centre Counties. Exposures of this formation are very poor. It consists principally of coarsely crystalline, thick-bedded, steel-blue dolomite with some thin-bedded, fine-grained dolomite. Interbeds of quartzite are common. The formation is characterized by a heavy residual mantle of sand and sandstone boulders weathered from the contained quartzite, and by a heavy growth of scrub pine and oak which has caused the land underlain by this formation to be termed "the barrens". The thickness of the formation is more than 1000 feet.

Weathering of feldspathic quartzite and argillaceous limestone beds in the formation has yielded locally thick, white and tan-colored clay. Many of these clay pockets contain nodular and massive manganese oxide ore, nearly always associated with iron oxides.

The manganese and iron oxides are replacements in the residual clay. Typical replacement features, similar to those in the ores of the Tomstown horizon, are recognizable. Colloform banding of the reniform ore and of some of the veinlets and beds of manganese oxide in the clay indicate that deposition and replacement processes involved precipitation from more or less colloidal solutions in a gel-like state. The manganese minerals are "psilomelane-type" and wad.

Many of the old iron ore pits which operated in the Gatesburg formation during the last century contain manganese oxides. Numerous pits were worked in that part of Blair and Huntingdon Counties included in the Tyrone quadrangle.

The source of manganese for the deposits may have been in the thick, semi-clastic beds which make up the middle and upper part of the formation. Direct evidence of this is lacking.

The grade of the massive ore, where it is not mixed with iron oxide, is good, ranging from 35 to 50 percent manganese. The manganese content of the mixed ore is low, probably no more than 10 percent.

Oxide ore in Ordovician limestone

Manganese oxide occurs as "psilomelane-type", pyrolusite, and wad accompanying the limonite, goethite and hematite ores that occupy pockets of residual tan and yellow clay in the Ordovician limestones. These limestones floor the Great Valley in Northampton, Lehigh, Berks, Lebanon, Cumberland, and Franklin counties, and the Chester and Lancaster Valleys in Chester, Lancaster, and York counties. Rarely do the manganese oxides achieve any significance in these limestones.

The brown Valley iron ores which were famous in Pennsylvania prior to 1910 were worked in hundreds of pits, some large, some

small, along the length of the Great Valley. The ores all occur in clay residual from weathering of the limestone and dolomite beds.[44] The ore is nodular, reniform, stalactitic, and massive in the form of stringers and thin beds in the clay. Where the ore is stalactitic and reniform, manganese oxide tends to be more abundant. This relationship, though not constant, is fairly consistent. There seems to be a close connection between the reniform structure and colloform texture of the iron oxides and the presence of manganese. The source of manganese is reasonably the same as the source of the iron. Frazer[45] thought the source was in the overlying "ferruginous slates". There is no conclusive evidence to prove whether the source was in the shales that overlie the Ordovician limestones or in the limestones themselves.

Locally, as in the Ironton pits of Lehigh County, the manganese oxide occurs as individual beds 6 inches thick and more. The ore mineral is "psilomelane-type", and the average manganese content is 35 to 40 percent. A similar occurrence of manganese oxide in the iron ore is at the Smyser bank northeast of York in York County. These occurrences are typical of those iron-ore deposits where downward percolating ground waters evidently carried manganese as well as iron. For the most part, however, the old pits did not and do not contain much manganese oxide associated with the iron. In most cases, the residual clays and the iron ores do not exceed a thickness of 75 feet; open cut mining usually extended to the bottom of the clays and did not, in the majority of cases, reveal an increase in manganese content with depth. Therefore, it is unlikely that many of the old Valley iron ore pits could ever be reopened on the basis of a possible significant manganese content at depth.

Oxide ore in Oriskany sandstone

Manganese oxides occurring as soft, structureless wad and siliceous "psilomelane-type" minerals have been seen at several places in the Oriskany sandstone in Franklin, Fulton, and Huntingdon Counties. There is a possibility that manganese oxide occurs in the Oriskany sandstone in the counties to the northeast also. It occurs as thin films coating the bedding planes and joint planes and as fissure fillings in opened planes; less commonly it occurs as partial replacement of the quartz grains in the sandstone.

Only one large deposit of ore of this type has been found in Pennsylvania though such deposits are numerous in Virginia.[46] In Huntingdon County, near Orbisonia, a deposit was formerly operated and produced mixed "psilomelane-type" and limonite ore. The manganese oxide ore was reported to average 35 percent of manganese.

Oxide ore in Chemung sandstone

Sandy phases of the Upper Devonian Chemung strata in Tioga, Bradford, Potter, and Lycoming Counties in northern Pennsylvania are occasionally impregnated with soft black manganese oxide. The

[44] Frazer, Persifor, Jr., The geology of Lancaster County: Penna. 2nd Geol. Survey, vol. CCC, pp. 203-208, 1880.
———————, Report of progress in York and Adams Counties: Penna. 2nd. Geol. Survey, vol. C., pp. 1-76, 1876.
Prime, Frederick, Jr., Brown hematite ore ranges of Lehigh County: Penna. 2nd. Geol. Survey, vol. D., 66 pp. 1875.

[45] Frazer, op. cit., p. 206.

[46] Stose, G. W., and Miser, H. D., Manganese deposits of western Virginia: Va. Geol. Survey, Bull. 22, p. 51, 1922.

sandstone beds all have very gentle dips, being in the Appalachian Plateau region. Slight warping of the beds, creating shallow and limited synclinal and flattened structures, has caused the deposition of manganese and, in some places, iron oxides in the porous strata.

Several small occurrences of this type were examined near Mansfield, Tioga County. The manganese oxide completely fills all the open spaces in the sandstone and it has also replaced the sandstone, creating a reticulate siliceous manganese ore where it crops out. The average manganese content of these ores is about 5 to 10 percent. None of these deposits is of commercial interest.

Oxide ore in Catskill sandstone and shale

Manganese oxides occurring as wad and the "psilomelane-type" minerals have been found at several places along joint and bedding planes in the red beds of the Catskill formation, and as scattered pieces and small nodules lying near the weathered surfaces of outcrops of the Catskill beds in Bedford, Fulton, and Huntingdon Counties; oxide has been reported associated with the Catskill beds in minute amounts from many other places in the State.

The manganese minerals occur in the red beds chiefly as thin films along joints and bedding. At some places the oxide has replaced shaly beds, forming thin beds and pockets of ore, and the nodular manganese found near weathered outcrops probably was so formed. The amount of manganese at any one place is very insignificant; the abundance of staining of the red beds by black films of oxide, however, is striking.

Oxide ore in Pocono sandstone

Manganese oxide minerals occur at many places in the Pocono sandstone of Bedford and Fulton Counties; small amounts of manganese oxide have been reported from the Pocono in central and northern Pennsylvania and the writer has seen thin films along joint planes in the Pocono sandstone in Blair and Centre Counties.

The minerals in Bedford and Fulton Counties are of the "psilomelane-type" and soft, structureless, black oxide. The manganese oxide occurs as impregnations and as fillings along joint and bedding planes in the top of the white and tan medium-grained Burgoon sandstone, the uppermost member of the Pocono. The black oxide also cements brecciated fragments and large angular pieces of sandstone float that lie on top of the Pocono formation along the dip slope of Rays Hill, south of the Broad Top region in Bedford County. Some of the oxides have partially replaced the sandstone.

The underlying structure has greatly influenced the location of deposits in the Pocono sandstone. They occur, for the most part, in the top portion of the gently northward-dipping sandstone along the south side of Sherman Valley, along the west side of Sideling Hill where the Pocono forms the dip slope, and in the large cove south of Wells Tannery where Sherman Valley and Coles Valley join each other. Relatively gentle monoclinal dips have been favorable to the accumulation and concentration of oxides.

The source of the deposits is clearly the manganese ore at the base of the overlying Mauch Chunk shale which has been partially dis-

solved and reprecipitated as an impregnation and as a replacement in the sandstone.

None of the deposits has been worked. None was observed which might even remotely approach commercial proportions. The quantity of ore in every case is very small and the nature of its occurrence as a highly siliceous rock with an average content of less than 5 percent of manganese precludes commercial operation of the deposits. The possibility of a large deposit under favorable structural conditions, such as a small infolded syncline, is not necessarily precluded, but no such favorable areas are known.

Oxide ore in bogs

Manganese occurs as an impure oxide, or series of oxides, in many bogs which abound in the flat, plateau country of northwestern and northeastern Pennsylvania. The oxide is part of the soft, earthy bog material; it colors the bogs black, or deep red-black if a relatively high content of iron oxide is present. The bogs have an average thickness of four feet, though they actually range from several inches to a reported thickness of 18 feet. None measured by the author was more than 10 feet thick. The areal extent of the bogs rarely exceeds 100 feet in diameter, though they are very irregular in shape. The possible tonnage from any single bog, therefore, is small.

The bogs occur on top of the horizontal beds of Pocono sandstone in northeastern Pennsylvania and near the top of the flat-lying Shenango sandstone series in northwestern Pennsylvania, which is the correlate of the Pocono formation. Active bogs are forming at many places in Venango County at this horizon, especially where there is a steep valley slope with talus blocks of the Shenango sandstone along it. The bog material is being deposited at the point where waters, which freely circulate through the talus, emerge as springs and are aerated. This oxidation causes precipitation of manganese oxides. The active bogs are depositing mainly iron oxides, but some manganese oxide is present. The source of the iron and manganese is most logically the horizon of the Mercer ore, approximately 150 feet above a rather constant level at which most of the bogs occur.

The manganese in five bogs examined in Venango County was less than three percent. In every bog examined in Pennsylvania, the material consists of a mixture of impure earthy manganese and iron oxides, never manganese oxides alone. There is little indication, from the number of bogs examined, that any may be much larger or contain a much greater manganese content. From a commercial standpoint, these bogs are valuable for use as a filtering medium for gases, and during both World Wars many small bogs were worked; some for this purpose. They have no immediate value on the basis of their limited metallic manganese content.

Oxide ore in Mauch Chunk shale

The second most important horizon at which manganese ore occurs in Pennsylvania is in the basal beds of the Mississippian Mauch Chunk shale in Bedford and Fulton Counties. Manganese minerals have also been reported from the same horizon at other places in the State.

The Mauch Chunk red shale disconformably overlies the Pocono sandstone in this area. The Loyalhanna limestone is missing. The thickness of the shale determined from several measured sections is about 1,000 feet. The shale is soft, very red, thin-bedded and laminated, with some massive sandier beds 10 feet thick near the base of the formation. In the basal 100 feet, there are several lens-shaped beds of dense red and blue-grey crystalline limestone 5 to 35 feet thick. The lowest of these is the so-called Trough Creek member. These limestone beds may reflect conditions similar to those where the Loyalhanna limestone was deposited, for they are siliceous and partly resemble the Loyalhanna. Thin beds of green shale and green and red sandstone are almost evenly spread throughout the section. All of the shale is sandy.

The Mauch Chunk shale is a soft formation lying between two hard, resistant formations, namely, the Mississippian Pocono sandstone below and the Pennsylvanian Pottsville sandstone above. Consequently, erosion has carved valleys in the shale almost everywhere. In Bedford and Fulton Counties, the large Broad Top coal basin is floored by resistant Pottsville sandstone which crops out with gentle dips on the south and east, forming steep escarpments. Surrounding the Broad Top coal field is a valley 800 to 1,200 feet lower than the scarp. This valley is floored everywhere by the Mauch Chunk shale. The Pocono sandstone underlies Rays Hill and Sideling Hill, and consistently forms a prominent ridge roughly parallel to the edge of the Broad Top field and separated from it by the "Mauch Chunk" Valley. The slope of these mountains on the side facing the Broad Top basin is nearly the dip slope of the Pocono sandstone.

The manganese minerals occur in the basal 50 feet of the Mauch Chunk shale. Cryptomelane is the chief mineral; there is also some soft black oxide. Both these oxides are associated with abundant iron oxide (limonite). The ore occurs as thin stringers along both joint and bedding planes and in tabular and lens-like masses parallel to the bedding where it has replaced the shale. The ore is essentially a replacement of basal beds of the Mauch Chunk shale by downward percolating manganese-bearing solutions. The path of the solutions may have been primarily along the contact of the shale and sandstone; but it is clear that some solutions percolated downward through the shale because so many of the joint planes are coated with thin films of manganese oxide. Replacement was active along thin laminae in the shale. Plane-banded colloform textures attest to growth by accretion in parallel planes and under conditions that apparently approximate those of precipitated gel-like material.

The source of the manganese minerals is unknown. Microscopic examination of the Mauch Chunk shale revealed no primary manganese minerals. However, the Mauch Chunk contains sandier lenses locally, and some of these more clastic beds may have been the source. The fact that the minerals are apparently concentrated only at certain places along a valley that seems to have constant structural conditions suggests that the deposits may be related to an original manganese content in certain parts of the formation. Possibly the source is still higher in the very clastic sediments of the Pottsville which floor the Broad Top basin. Careful examination of the Potts-

ville series does not substantiate this assumption. The manganese minerals at their primary source were probably so scattered that there would be little evidence of them.

Oxide ore in underclay

Manganese oxide in the form of thin veinlets and soft, structureless wad occurs in some of the sandy underclays of the Bernice coal field in northeastern Sullivan County. The presence of manganese has also been noted in the analyses of some clays from Cambria County; these clays are unimportant, but some of the underclays in the other small coal fields in the plateau country of Wyoming, Bradford, Lycoming, and Tioga Counties, may contain important amounts of manganese oxide.

The average content of manganese is less than five percent in the Bernice underclay. More than half is of a replacement nature, manganese-bearing solutions having attacked the quartz in the clay and raggedly replaced it. Occurrences such as this have no commercial value.

HYPOGENE DEPOSITS

With possibly one exception, hypogene manganese minerals in Pennsylvania are only of mineralogic interest; they have no commercial importance. There are very few localities where hypogene minerals occur. At Cornwall, in Lebanon County, rhodochrosite, rhodonite, and cobaltiferous crednerite, the latter a rare copper-manganese oxide, have been found in the western magnetite ore body.[47] These minerals have been largely removed by mining operations. Rhodochrosite is still found occasionally. At Saint Peters, in Chester County, there is evidence that small amounts of manganese minerals were introduced along with the main magnetite ore body.[48] Pyrolusite has been reported from the mines. It may be hypogene, but it is more likely an alteration product of the more usual hypogene mineral, manganite. Since no specimens were available for study, this is only a supposition based on known alterations elsewhere.[49]

Spessartite, tephroite, and associated rarer manganese-bearing minerals which occur in the crystalline gneiss rocks of southeastern Pennsylvania are probably all of hypogene origin.

At the Reading Banks ore pit, near Boiling Springs in Cumberland County, small veinlets of manganite cut the residual deposits of mixed cryptomelane-limonite ore in the base of the Tomstown dolomite. The manganite is associated with vein quartz which may be hypogene.[50] Manganite is more commonly a hypogene mineral and this occurrence may be hypogene. There is very little of it present; however, a more detailed examination of the area, and of similar areas in this horizon along the Appalachian Valley may show greater quantities of manganite, as well as some diagnostic features to prove hypogene or supergene origin. Associated as it is with the supergene ore, it has possibly commercial importance; alone it has none.

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[47] Genth, F. A., Mineralogy of Pennsylvania: Penna. 2nd Geol. Survey, vol. B, pp. 54, 161, 1875.

[48] Smith, L. L., Magnetite ore deposits of French Creek, Pennsylvania: Penna. Topog. & Geol. Survey Bull. M 14, p. 43, 1930.

[49] Thiel, G. A., The manganese minerals; their identification and paragenesis: Econ. Geol., vol. 19, p. 126, 1924.

[50] Schwartz, G. M., Microscopic criteria of hypogene and supergene ores: Econ. Geol., vol. 27, pp. 533-553, 1932.

MINERAL ASSOCIATION

The ore minerals of manganese found in Pennsylvania include cryptomelane, psilomelane, pyrolusite, manganite, and wad; of these, cryptomelane is by far the most important. Only supergene minerals are important as ore minerals. Because the deposits of manganese minerals are almost solely of supergene origin, the minerals associated with the manganese ore minerals are typical of supergene deposits, being either of supergene origin themselves or residual from replaced sedimentary beds. A brief description of the associated gangue and ore minerals follows:

Gangue minerals. The most common gangue mineral is quartz. Nearly all sedimentary beds contain quartz, whether they are sandstone, limestone, or shale. In the sedimentary beds which manganese oxide has replaced, quartz is present in fairly large quantities. Although it has suffered some replacement in many of the deposits, it has been but little replaced in comparison to minerals like calcite, dolomite, and sericite. The nature of the quartz, of course, varies, its character depending on its original nature in the sedimentary beds and the amount of replacement which has taken place. The quartz ranges in size from tiny, rounded grains less than .03 mm. in diameter to pieces of quartzite and individual quartz grains more than 8 mm. in diameter. The small grains are frequently aligned in the manganese, indicating directions of flow of the mineralizing solutions. Strained quartz, showing undulatory extinction, is often cracked, and more often replaced along both the cracks and the edges than unstrained quartz.

Carbonate is a gangue mineral in the Mauch Chunk deposits, but it is not common, most of the carbonate having been replaced by ore. The carbonate grains are small, averaging about .5 mm. in size. Smaller grains constitute the matrix in some of the rocks.

Sericite is an abundant gangue mineral in partly replaced shales. In arenaceous shales, sericite is the mineral most completely replaced. It occurs as fibrous and small platy grains which average between one micron and .05 mm. in diameter. Much of the sericite is an original constituent of the sedimentary rock; some of it, however, is secondary, altered from feldspar minerals.

Associated with sericite, and in rocks that once contained a considerable percentage of sericite now replaced by manganese oxide, kaolinite is an occasional gangue material. Structureless, soft tan and white kaolinite is an alteration from sericite and feldspar.

Rarely, grains of orthoclase and plagioclase are associated with the manganese ore minerals, all of them much rounded from erosion and partly altered to kaolinite.

Heavy minerals like zircon, tourmaline, and some questionable apatite, are relatively unreplaced and unaffected by the manganese solutions which permeated and replaced arenaceous shale and sandstone beds. Other heavy minerals are lacking. This is a direct reflection of the age of the sediments replaced by manganese solutions. Paleozoic sediments are so old that only the most stable heavy minerals, like zircon, retain their identity; all the others, like the pyroxene and amphibole minerals and magnetite, have been destroyed.

Chalcopyrite is an uncommon mineral identified in the oxide deposits of the Mauch Chunk shale. Several small grains were observed all rounded, all of sedimentary origin.

Ore minerals. The chief associated ore mineral is iron oxide. It occurs with the manganese oxide minerals in nearly all the occurrences of the State, and wherever manganese oxide is present in abundance, iron oxide is a prominent associated mineral.

Most of the iron oxide is limonite. The physical and chemical properties vary considerably from one occurrence to another and at some localities, such as Reading Banks, there are two distinct generations of limonite with very different physical and optical properties. Though primary limonite occurs in the Mauch Chunk shale in Bedford County, nearly all the limonite is of secondary, supergene origin.

The limonite is usually a replacement mineral, like the manganese oxides with which it is associated. It occurs as irregular masses, tabular replacements influenced by bedding and laminations, and cross cutting veins. In addition to the replacement type, limonite occurs as fissure fillings along joints and fractures, as impregnations in porus talus-like areas, and in precipitated, stalactitic forms deposited in open cavities. These modes of occurrence are all closely related to similar modes of occurrence of manganese oxides; rarely does the limonite occur differently from the manganese oxide associated with it. Obviously the reaction of iron-bearing and manganese-bearing solutions to a similar environment is similar.

At most of the occurrences where iron and manganese oxides are associated, iron minerals are very slightly earlier than the manganese minerals which cut across them. However, the distinction is often a fine one, for the two series of oxides were apparently carried in one solution and often precipitated from the solution at the same time, forming confused masses of cross-cutting, alternate-bedded, and irregular replacement ore.

The textures developed in the iron oxides, like the physical forms, are similar to those in the manganese oxides. Colloform texture is the most common type, being especially well developed in iron oxides having reniform and botryoidal structure. These structural forms owe their shape to concentric growth by colloform banding.

Goethite, golden yellow and crystalline, occurs as small lens-like late replacements in the manganese oxide minerals at Reading Banks, Cumberland County. It has been formed as a late mineral from dominantly manganese-rich solutions which resorbed part of the early limonite in the ore mass.

DISTRIBUTION OF MANGANESE MINERALS IN PENNSYLVANIA

General Discussion

There are more than 70 occurrences of manganese minerals in Pennsylvania; most of the locations are shown on Figure 6. These localities are divided into three categories:

1. Commercial possibilities.
2. Occurrences visited and examined.
3. Reported occurrences.

Three localities are classed as commercial possibilities. The geology and ore deposits of two of them are fully discussed in this report. The third locality is fully described in a separate report.[51] Descriptions of the other occurrences are arranged according to counties; numbers in the text correspond to numbered localities on the map. The localities on the map are listed in Table 6 with the type of occurrence. No manganese minerals have been observed or reported from 40 counties.

General features of the widespread occurrence of manganese minerals in Pennsylvania noted in Figure 6 are:

1. There are no important occurrences in the Appalachian Plateau province, which includes the western, northwestern and northern parts of the State, nor in the Piedmont and Triassic provinces of the southeastern part of the State.
2. The greatest number of occurrences is aligned in the northeast-southwest-trending belt of the Great Valley.
3. The commercial possiblities are limited to the Great Valley and the south-central and central parts of the Ridge and Valley province.

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[51] Foose, R. M., Iron-manganese ore deposit at White Rocks, Cumberland County, Pennsylvania: Pennsylvania Geol. Survey Bull. M-26, 1945.

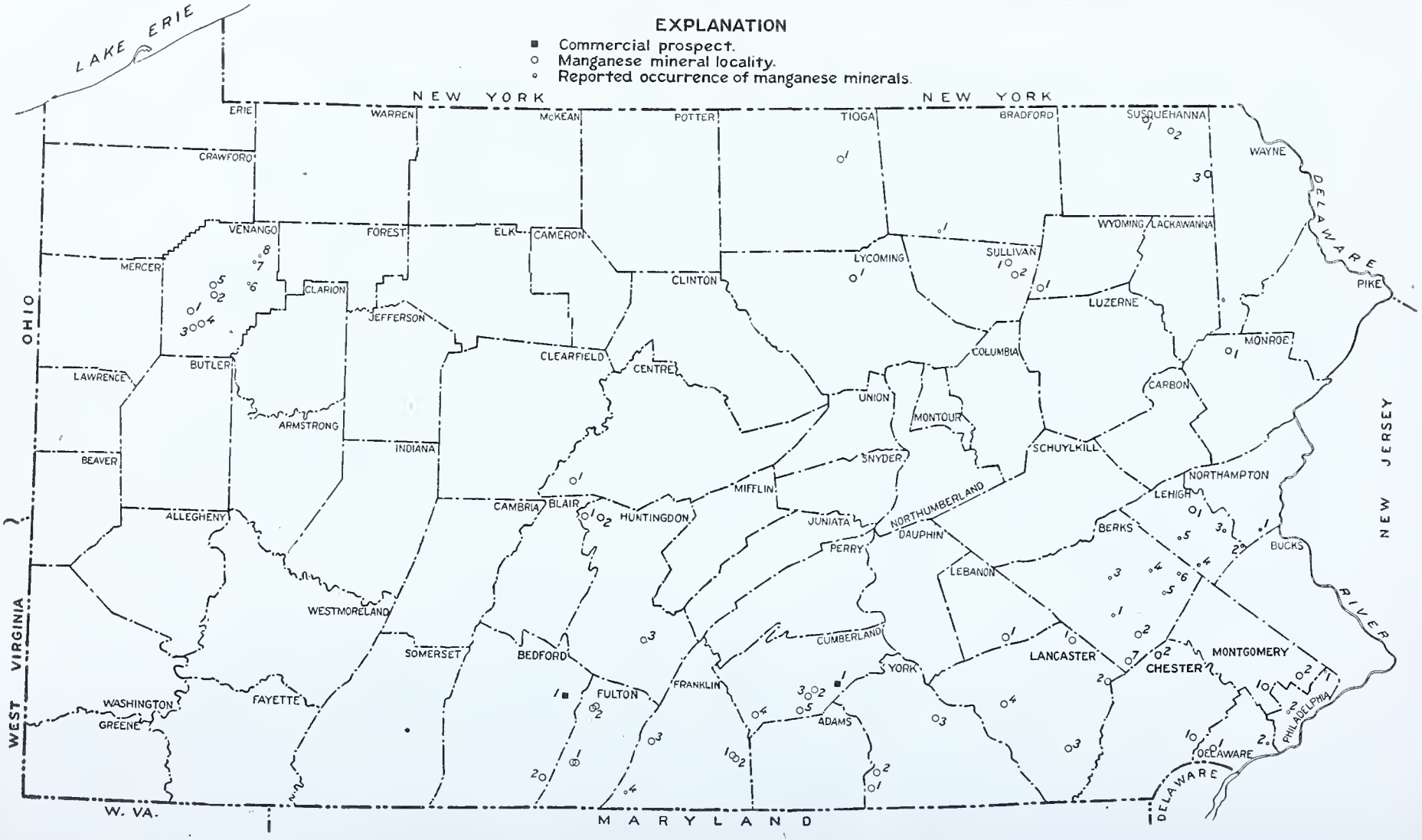

Figure 6. Index map to manganese localities of Pennsylvania.

Table 6. Manganese Mineral Localities

Locality	Associated Formation[1]	Type Occurrence	Prospect[2]
Bedford County			
Sherman Valley(1)	Discussed under commercial possibilities		A
McKees Gap(2)	Catskill	Stains, nod.	B
Berks County			
Morgantown Road(1)	Tomstown	Resid., nod.	B
Birdsboro(2)	Triassic ss	do	B
Maiden Creek(3)	Tomstown	do	B
Lyons(4)	do	do	B
Manatawny(5)	do	Resid., bed.	B
Gehman tract(6)		Assoc. with iron ore	B
Joanne Station(7)	Triassic ss	Replace.	B
Bradford County			
Barclay basin(1)	Mauch Chunk	Resid., nod.	B
Centre County			
Wrye Bank(1)	Gatesburg	Resid., nod. & bed.	A
Chester County			
Sharpless farm(1)	Gneiss	Resid.	B
Saint Peters(2)	Gneiss & Triassic ss	Assoc. with iron ore	B
Cumberland County			
Reading Banks—White Rocks	Discussed under commercial possibilities		A
McCarrick prospect(2)	Antietam	Resid., nod.	B
Wharton mine(3)	do	do	A
Clever Banks(3)	Tomstown	Assoc. with iron ore	B
Laurel Banks(5)	do	Resid., nod.	B
Delaware County			
Garnet mines(1)	Gneiss	Resid.	B
Darby(2)	do	do	B
Franklin County			
English Bank (1)	Tomstown	Resid., nod. & bed.	A
Promise Bank(2)	do	do	B
Squire Stinger Bank(3)			B
Little Cove Area(4)	Oriskany	Impreg & replace.	B
Fulton County			
Needmore Area(1)	Catskill	Stains, nod.	B
Oregon Run Area(2)	Mauch Chunk	Resid., nod.	A
Huntingdon County			
East Pennington Bank(1)	Gatesburg	Resid., nod. & bed.	A
Huntingdon Furnace(2)	do	Resid., nod.	A
Orbisonia Area(3)	Oriskany	Impreg. & replace.	B
Lancaster County			
East Cocalico Twp.(1)	Ordovician ls.	Resid.	B
Beartown(2)	do	do	B
Quarryville(3)	do	do	B
Silver Spring(4)	do	Resid. with iron ore	B
Lebanon County			
Cornwall(1)	Ordov. ls. & Triassic	Assoc. with iron ore	B
Lehigh County			
Ironton Banks(1)	Ordovician ls.	Resid., nod. & bed.	B
Wharton mine(2)	Antietam	Assoc. with iron ore	B
Emmaus mines(3)		Resid., nod. & bed.	B
Alburtis(4)	Tomstown	Assoc. with iron ore	B
Fogelsville(5)	do	do	B
Lycoming County			
Slacks Run Area	Catskill or Pocono	Replace & impreg.	B

Table 6. Manganese Mineral Localities—Continued

Locality	Associated Formation[1]	Type Occurrence	Prospect[2]
Monroe County			
Tobyhanna Area(1)	Pocono	Resid. & bogs	B
Montgomery County			
Spring Mill (1)	Gneiss	Resid.	B
Edge Hill(2)	do	do	B
Northampton County			
Saucon Twp.(1)	Tomstown	Resid., nod.	B
Philadelphia County			
Pennypack Creek(1)	Gneiss	Resid., nod.	B
Fairmount Park(2)	Recent drift	Bedded	B
Sullivan County			
Dempsey Bog(1)	Pocono	Bog	B
Lopez(2)	Underclay	Impreg. & replace.	B
Susquehanna County			
Great Bend(1)	Catskill	Bog	B
Susquehanna(2)	do	do	B
Chubbuck Property(3)	do	do	B
Tioga County			
Mansfield Area(1)	Chemung	Impreg. & replace.	B
Venango County			
Victory Hollow(1)	Mississippian	Bog	B
Brundred Lease(2)	do	do	B
River Ridge(3)	do	do	B
Kennerdell(4)	do	do	B
Bullion Hollow(5)	do	do	B
Wyoming County			
Dutch Mountain(1)	Pocono	Impreg. & bogs	B
York County			
Louis Delone Bank(1)	Ordovician ls.	Resid., assoc. with iron ore	B
Haldeman & Bechtel Banks(2)	do	Assoc. with iron ore	
Smyser Bank(3)	do	do	B

[1] See Table 2.
[2] A = worth prospecting; B = not worth prospecting.
Abbreviations: Nod. = nodular, Resid. = residual, Bed. = bedded, Impreg. = impregnation, Replace. = replacement.

Factors which have influenced the distribution of manganese minerals have been discussed in an earlier chapter.

COMMERCIAL POSSIBILITIES

SHERMAN VALLEY AREA[52]

Location and General Description

Sherman valley[53] is located in Bedford County, six miles northeast of Everett and four miles south of the borough of Hopewell (fig. 7). It is bounded to the northwest by the Broad Top coal field, which rises about 900 feet above the floor of the valley, forming a scarp at the top. To the west and the southwest the valley is bounded by Rays Hill, which bends sharply back upon itself, forming an acute angle at the southwestern end of the valley. The valley widens to the northeast and east into a broad irregular-shaped lowland limited by Sideling Hill on the east. The well-defined valley is six miles long and the irreguiar valley area on the east is roughly five miles in diameter. Coles Valley is a narrow valley about nine miles long, which extends northward from the northeast end of the wide valley and is closely bounded by the Broad Top coal field on the west and Sideling Hill on the east. This area is included in the Everett and Broad Top topographic sheets.

Two miles east of Cypher Station along the macadam road running through the southwestern part of Sherman Valley, manganese ore and manganiferous iron ore have been produced during several short intervals through a period of more than 60 years. The property is jointly owned by Mr. Harry Simon of Hopewell, Pennsylvania, and Dr. J. G. Coles of Schwenksville, Pennsylvania.

History of mining and production on the Coles-Simon property[54]

About 1890 a company was organized which included several men actively engaged in the operation of the Riddlesburg Furnace at Riddlesburg, two miles north of Hopewell on the west edge of the Broad Top coal field. On the property in Sherman Valley this company drove an untimbered drift more than 70 feet long, approximately N.70°E., parallel with the valley floor, and less than 15 feet below the surface. Part of the drift remains unslumped and accessible. It is evident that it was driven in the top beds of the Mauch Chunk red shale, and even partly in the overlying weathered residuum and float from Rays Hill, along the trace of black smudges and stains which were made by superficial manganese oxide coating bedding and joint planes in the shale. No solid ore of any kind is visible in the drift.

The same company dug a trench from the south toward the present open cut and, at the location of the present working, sank a shaft reported to be 60 feet deep. The shaft has caved and the trench is no longer evident. Some ore is supposed to have been removed from these workings and smelted at the Riddlesburg Furnace, but the manganese content made the resulting pigs undesirable, and they were discarded on the slag dump.

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[52] Considerable space is given to discussion of the stratigraphy and especially to the structure of this area, some of it having little obvious relation to the known occurrence of ore minerals. Because of the large size of this area and the possibility that commercial concentrations of ore minerals may occur at locations now unknown, these data are included to make the geologic picture as complete as possible.—R.M.F.

[53] Also called Ground Hog Valley.

[54] Details of historical background supplied by Messrs. Harry and James Simon of Hopewell.

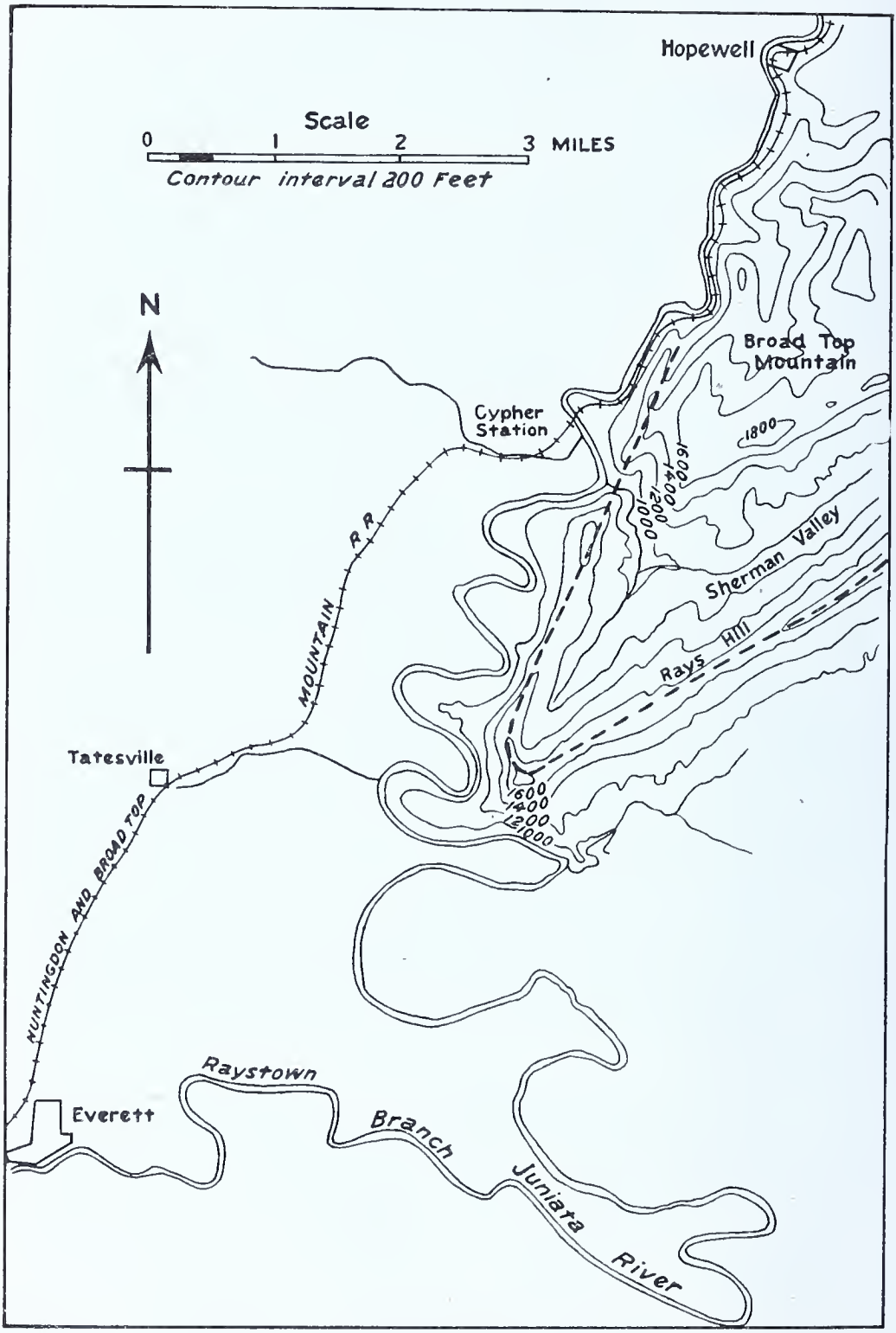

Figure 7. Index map showing location of Sherman Valley area.

About 1910 several men from the vicinity of Hopewell sank a 6-foot diameter shaft to a depth of 35 feet about 75 feet south of the macadam road and close to the drift that was driven about 1890. The shaft is reported to have encountered ore at a depth of 25 feet lying above limestone. This report is not substantiated and apparently no ore was ever removed. At the same time, and presumably by the same men, a shaft was sunk on the property adjoining to the northeast. At 30 feet no ore was encountered and all operations were abandoned.

The property was not worked again until 1919. At that time, Mr. Harry Simon and Dr. J. G. Cole, both of Hopewell, and owners of the property, began operations to remove ore. They drove a 30-foot drift S.40°E. into the hill slope about 150 yards north of the present operations, and from a point 15 feet above creek level. The drift has long since slumped; no ore was encountered, but the Mauch Chunk red shale, which was penetrated, showed abundant black manganese oxide stain. The face of the drift was only about 15 feet below the surface, so only weathered shale and the overlying mantle were penetrated by it.

At the same time they drove a slope at the site of the present operations which trended N.27°E. and had an inclination of 12 to 14 degrees. The length of the slope was 70 feet. When first visited by the writer in 1940, the portal had slumped and it was impossible to gain entrance. The open-cut development of late 1940, however, exposed the slope, and it was examined to within 10 feet of the face where the water level met the roof. The slope ran in ore all the way. The ore is massive, bedded, brown and black manganiferous iron oxide mixed with red shale. Five carloads of run-of-mine ore were shipped from the slope to the Riddlesburg Coal and Iron Company and smelted in the furnace at Riddlesburg. The slope was worked very irregularly for a period of four years until 1923 when all activity ceased.

During the same period of mining, about 1920, a shaft was sunk to a depth of 30 feet near the location of the shaft sunk about 1910 and 15 feet south of the slope portal. No solid ore was penetrated, but red shale coated by films of manganese oxide was common.

In 1940, the two owners became interested in opening the ore near the site of the slope driven in 1919. During December 1940, a steam shovel was placed on the property just south of the macadam road, and an open cut was dug. The cut, semi-circular in shape, opens onto the macadam road at both ends, the two ends being 300 feet apart. It is accessible only from the southeastern end because the ore face is developed near the northeastern end. It is 30 to 60 feet wide and about 25 feet deep near the ore face. The ore face stands about 6 feet high and extends 30 feet across the cut. This operation revealed the locations of the drift driven about 1890, the two shafts sunk about 1910 and in 1919, and made accessible the slope driven in 1919. (See figure 8.)

Two carloads of ore were shipped to the Alan Wood Steel Company in Conshohocken, Pennsylvania, in December 1940. Operations were suspended in June 1942, when the owners tried selective mining

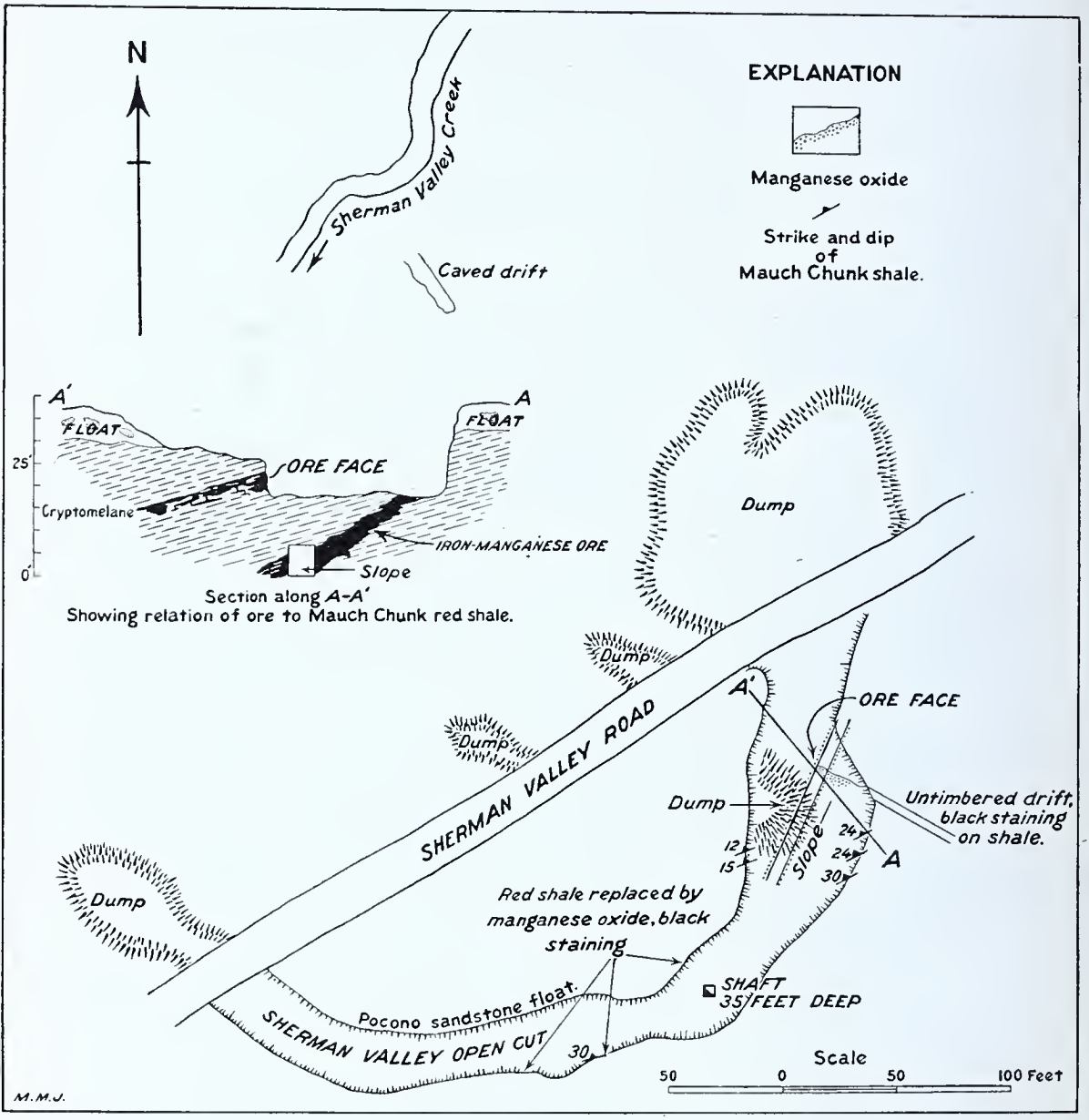

Figure 8. Aereal map and cross section of the Sherman Valley open cut.

and shipped 23 tons of more-than-45-percent ore to E. J. Lavino Company. There has been no mining since that time.

Approximately 600 tons of ore have been mined from the property since it was first worked. Of this, there is record of shipment of 400 tons during the period 1919-1923, about 100 tons in 1940, and 23 tons in 1942. About 100 tons of ore, averaging 30 percent of manganese, can be obtained from several of the dumps across the macadam road directly north of the open cut. The only attempt at selective mining was made in a crude way during 1940 and with more care in 1942. The average manganese content of ore shipped from 1919 to 1923 was slightly more than 10 percent; during 1940, when crude handpicking of the ore chunks was practiced, the content was

slightly more than 20 percent; and in 1942, it was better than 45 percent.

Recent Exporation

On the basis of information published in Progress Report 128,[55] the Bureau of Mines, U. S. Department of Interior, decided to explore the Coles-Simon property by drilling. During October-November 1942, two bucket drill holes, 18 feet and 57 feet deep, were drilled north of the Sherman Valley open cut, across the macadam road, and down the dip from the ore face. (Figure 16.) Difficulties in operation of the drill prevented both holes from being drilled to the top of the Pocono sandstone, and thus through the "ore-bearing" basal beds of the Mauch Chunk shale, as recommended by the State Geological Survey. Little ore was encountered in the shallow hole; a zone of thin veinlets of cryptomelane and wad was encountered between 25-30 feet in the deeper hole. Because the basal beds of the Mauch Chunk shale were not penetrated, the drilling was considered unsatisfactory.

In December 1942, two new holes close to the location of the bucket-drill holes were sunk by churn drill. These holes were approximately 50 and 70 feet deep. Although the importance of drilling through the basal beds of the Mauch Chunk shale was obvious, both holes were stopped short of the Pocono sandstone. Examination of the chip samples from both holes corroborated the bucket drill data, to the depth that those holes had been drilled, and showed small amounts of manganese minerals in the deeper parts of both churn drill holes.

It is possible that both churn drill holes, especially hole No. 2, penetrated enough of the basal beds of the Mauch Chunk shale to indicate an absence of ore down the dip from the ore face in the open cut. However, there is no proof of that. On the basis of the results from these four incomplete drill holes, the property could not be condemned as having little or no ore.

General Geology

Physiography

This area lies in the Middle Section of The Ridge and Valley province of the Appalachian Highlands.[56] The physiographic details of this area are at once interesting and complicated. Probably in no other region of Pennsylvania is there such an unusual abundance of different topographic features and anomalous physiographic relations.

The mountains of the region are relatively even-crested, attesting to a former peneplain, the Schooley surface, which was developed during Tertiary time.[57] The crests of Evitts, Dunning and Tussey Mountains to the west of Sherman Valley average between 2,000 and 2,500 feet, and the crests of Rays Hill and Sideling Hill south and east of Sherman Valley average between 1,800 and 2,000 feet, indi-

[55] Foose, R. M., Manganese minerals of Pennsylvania: Pennsylvania Geol. Survey Progress Report; pp. 11-16, 1942.

[56] Fenneman, N. M., Physiography of the eastern United States, p. 230, New York, McGraw-Hill Book Company, 1938.

[57] Ashley, G. H., Age of the Appalachian peneplains: Bull. Geol. Soc. Am., vol. 41, pp. 695-700, 1930.

eating a general eastward slope of the old surfaee. The mountain erests trend generally N.20°E., but structural anomalies eause many departures from the general trend and create a sinuous arrangement of mountain erests. The prominent ridge makers in the region are the Pottsville sandstone (Pennsylvanian) whieh holds up the Broad Top eoal field, the Poeono sandstone (Mississippian) whieh holds up Rays Hill and Sideling Hill, and the Tusearora sandstone (Silurian) whieh holds up Tussey, Evitts, and Dunning Mountains.

The valleys are of two types: Narrow and steep walled, like Sherman Valley, and broad and eove-like, sueh as the wide valley area around Wells Tannery east of Sherman Valley. The maximum relief in the immediate vieinity of Sherman Valley is 1,500 feet; the average relief of the area is 800-900 feet. The Mauch Chunk shale (Mississippian), the Upper Devonian shales, and the Ordovieian limestones are the dominant valley rocks.

Drainage. The master stream of the area is the Raystown Braneh of the Juniata River whieh flows generally south, then east, then northeast, eutting aeross Evitts and Tussey Mountains and flowing elose along the western side of Rays Hill, meandering strongly all the way. Mueh has been written about the strong meandering nature of the river. Where it flows alongside Rays Hill the meanders are eontrolled in part, at least, by the underlying roek strueture. Sherman Valley Creek flows southwestward in Sherman Valley and enters the Raystown Braneh at Cypher Station where faulting has helped eontrol the drainage outlet through Rays Hill.

There are both dendritie and trellis drainage types in the area. Where resistant sandstone ridges are the ehief struetural and topographie feature, trellis drainage prevails.

Stratigraphic Succession

General statement. The roeks of the Sherman Valley area are all sedimentary roeks of later Paleozoie age. They inelude the Portage and Chemung brown shales and sandstones and the Catskill red beds of the Upper Devonian; the Poeono sandstone and the Maueh Chunk red shale of the Mississippian system; the Pottsville formation, and the eoal-bearing Allegheny formation in the Broad Top eoal field, of the Pennsylvanian system. The total thiekness of these sedimentary roeks in this area approximates a minimum of 9,200 feet. (See Table 7.) All of the roeks are folded and the degree of folding is relatively intense. However, none of the roeks are metamorphosed. The fold axis of the Broad Top basin, the flanks of whieh inelude Rays Hill and Sherman Valley, plunges about 18 degrees in the direetion N.25°E. It is this plunge that eauses the Poeono sandstone whieh holds up Rays Hill to ehange its strike sharply from N.20°E. to N.65°E. These two trends are the most eommon in the region, though the rocks strike at all angles between the two.

The roeks in Table 7 will be deseribed on the sueeeeding pages; full and complete treatment, however, is given only to the Poeono and Maueh Chunk formations beeause those two are the manganese-bearing formations in the area.

Table 7. Stratigraphic succession in the Sherman Valley area

Age and Formation	Character	Thickness (feet)
PENNSYLVANIAN		
Allegheny	Tan sandstone, coal beds, some shale.	250-275
Pottsville	White to tan massive sandstone.	250-300
	Disconformity	
MISSISSIPPIAN		
Mauch Chunk	Red shale with thin green interbeds, and some sandstone; ore-bearing in basal part at some places.	1,000
	Disconformity	
Pocono	Light green and tan, medium grained sandstone; ore-bearing in topmost beds at some places.	500-600
DEVONIAN		
Catskill	Red and green sandstone and shale.	3,000±
Portage and Chemung	Brown and tan shale and sandstone.	4,000±

DEVONIAN

Portage and Chemung formations

General description. The Portage and Chemung formations are of Upper Devonian age. They include the youngest Devonian marine strata in the area and also contain many continental beds. The total thickness of the Portage-Chemung beds exceeds 4,000 feet. These beds underlie a large part of the valley region that is parallel to the outline of the Broad Top coal field on the west and south; they are separated from Rays Hill by the Catskill formation. Outcrops of the formations are usually deeply weathered.

Lithologic description. The Portage and Chemung are characterized by beds of grey, green, and brown shale and shaly sandstone, black shale, and some thin beds of tan sandstone and conglomerate. The brown shales are largely in the uppermost Chemung and the lowermost consists of the grey and green beds. A few red beds are near the top.

Catskill formation

General description. The Catskill formation includes the youngest Devonian beds. They are continental beds which lie conformably upon and also interfinger with the lower marine Chemung. In this area the Catskill formation is about 3,000 feet thick. It underlies the Rays Cove region and the lower land immediately adjacent to Rays Hill on the west and south. Where the Catskill is sandy, outcrops of the formation are numerous and fresh.

Lithologic description. The Catskill formation consists chiefly of thin-bedded red and green shale. The red shale commonly masks the presence of the green beds in weathered sections. Interbedded with the shale are thin beds of red and grey-green fine-grained sandstone, frequently cross-bedded and ripple marked. Though most beds are thin-bedded, massive beds occur too.

MISSISSIPPIAN

Pocono formation

General description. The Pocono formation conformably overlies the Catskill beds of the Devonian and is the basal Mississippian formation. The Pocono formation is one of the three main ridge makers of this area. It holds up Rays Hill and Sideling Hill surrounding the Broad Top coal field on all sides. The thickness of the Pocono in this region is between 500 and 600 feet. Though it is a hard, resistant ridge maker, outcrops of the Pocono are not very abundant, but they are fresh and relatively unweathered.

Lithologic description. The Pocono formation consists of a sandstone in the uppermost part, the Burgoon, and of grey and red shale and grey-green sandstone and quartzite in the lower part. In this region Reger[58] has subdivided the Pocono formation into four members: The topmost member is the thick, massive-bedded, coarse-grained, yellowish Burgoon sandstone, about 200 feet thick. Below it are successively the Riddlesburg shale and the Broad Ford sandstone, and at the base is the Berea sandstone, a medium-grained, grey-green, partly quartzitic rock. Thin beds of coal, ranging from two to six inches, occur in the Burgoon. One of these beds can be seen in the topmost Burgoon where it crops out in the gap through Sideling Hill at New Grenada. The basal Pocono, where it is in contact with the underlying Catskill shale at the gap in Rays Hill, half a mile south of Cypher Station, varies from a medium-grained purplish sandstone to a coarse-grained, almost conglomeratic, grey-green, cross-bedded rock. The uppermost Pocono beds also contain small pockets of iron oxide.

Petrographic description. The Pocono formation is too variable to be simply described. The texture is quartzitic and the grains are anhedral.

Approximately 90 percent of the rock consists of sub-rounded to sub-angular grains of clear quartz. The grain size, for the most part, ranges from 1 to 3 millimeters. The quartzitic facies at the base of the Pocono has grains ranging from .13 to .5 mm. in diameter; these have serrate edges and are closely interlocked in quartzitic texture (pl. 27, B). Smaller grains of quartz, .01 mm. in diameter, mixed with the same sized grains of sericite, form a cement between the larger quartz grains. Secondary growth of quartz, capping original grains, attests to some metamorphism by pressure, causing solution of silica and later deposition on quartz grains (pl. 27, B).

About 5 per cent of sericite is usually present as small fibers and plates; when the rock is shaly much more is present. The sericite is primary. The average diameter of the flattened platy grains is .01 mm.

Other accessory minerals include small amounts of tourmaline, zircon, and chlorite.

As a superficial mineral, limonite is present in the formation at many places, usually most abundant where the rock is coarser grained or better jointed. It occurs in two ways: as black grain-like areas

[58] Reger, D. B., Pocono stratigraphy in the Broad Top Basin of Pennsylvania: Geol. Soc. Amer. Bull., vol. 38, No. 2, pp. 405-407, 1927.

and as thin films. Though the grain-like spots appear to be primary limonite grains, they are secondary, as evidenced by their development where widespread films of limonite become thicker and coalesce into small dark areas.

Structural description. The Pocono sandstone is a competent, hard, and resistant formation that trends in every possible direction in the region. The two main trends, however, are N.20°E. and N.65°E.; as where the formation bounds Sherman Valley with two limbs of an asymmetric syncline plunging northeast. The dip of the formation averages 70°SE. on the northwest limb of the syncline and 20° to 40°NW. on the southeast limb of the syncline.

Joints are fairly well developed, but exposures of the Pocono are too few to gain a complete picture of the joint pattern. There is a definite set of cross joints which "swings around" the two limbs of the syncline and is always approximately 90 degrees to the strike of the beds (pl. 1, in pocket). Joint readings, plotted in figure 9 as the poles of joint planes, show this.

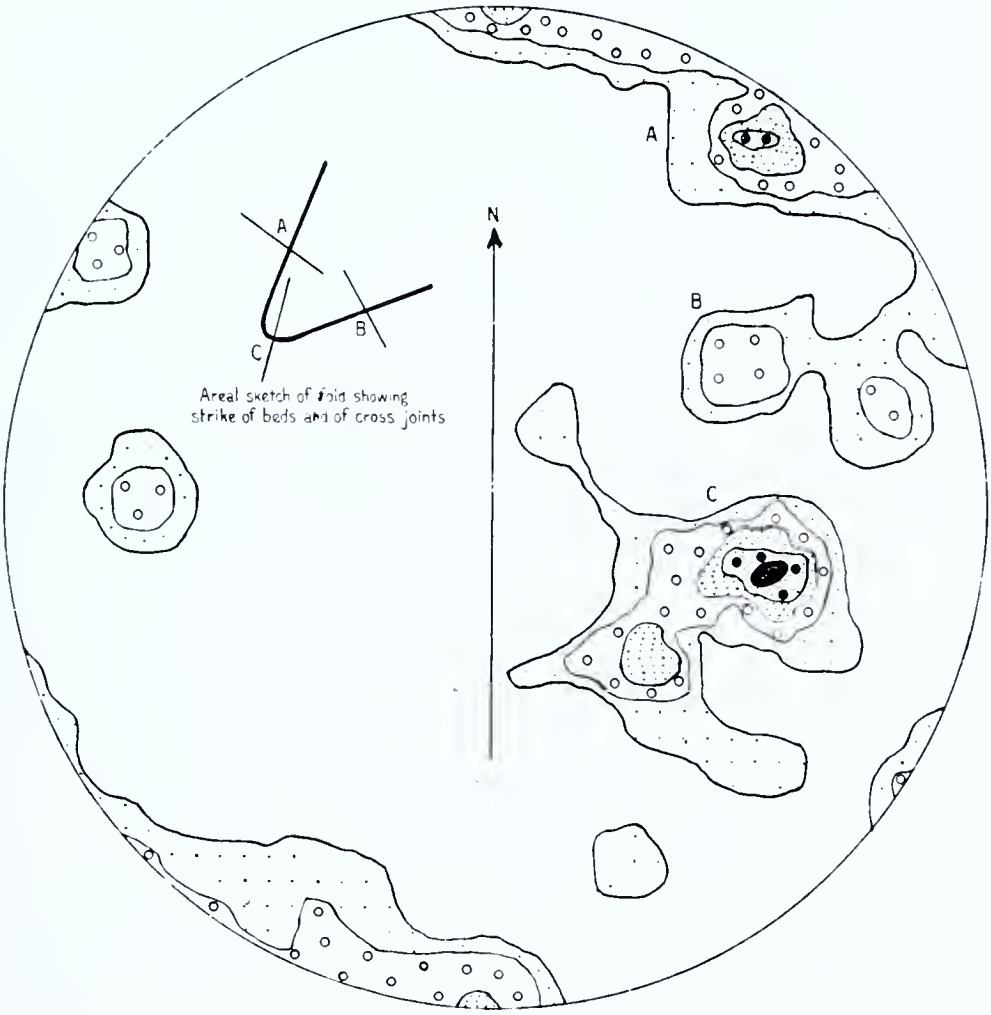

Figure 9. Joints in the Pocono sandstone and their relation to the large fold in Sherman Valley. Data based on 125 joint measurements; contoured on 1, 4, 8, 12, and 15 percent.

Though it seems fairly certain that cross faults of small displacement cut across the Pocono sandstone in Rays Hill, actual faulting of this nature was seen and measured at only one place. In the southwest corner of Sherman Valley an old woods road runs south across Rays Hill. Along this road at an elevation of 1,480 feet a poor exposure of Pocono sandstone has a faulted surface which strikes N.7°E. and dips 30°E. The bedding strikes N.23°E., dips 80°NW. and is clearly dragged out of the normal N.65°E. trend. Slickensides on the fault plane strike N.69°W. The fault, therefore, is a reverse fault with the east side moving west and north. Displacement could not be measured. Erratic trends of the bedding in the valley indicate the fault extends north across the Mauch Chunk-Pocono contact. This is not proved.

Linear structures in the "ac" plane, or the plane perpendicular to the fold axis, are evident in the Pocono formation at a few places where striations have developed parallel to the dip due to beds slipping over each other during folding. This is perhaps best shown on the bedding face of a large outcrop 150 yards southwest of John Warsing's house on the south side of the road in southwestern Sherman Valley (fig. 10). This linear direction is a direct result of

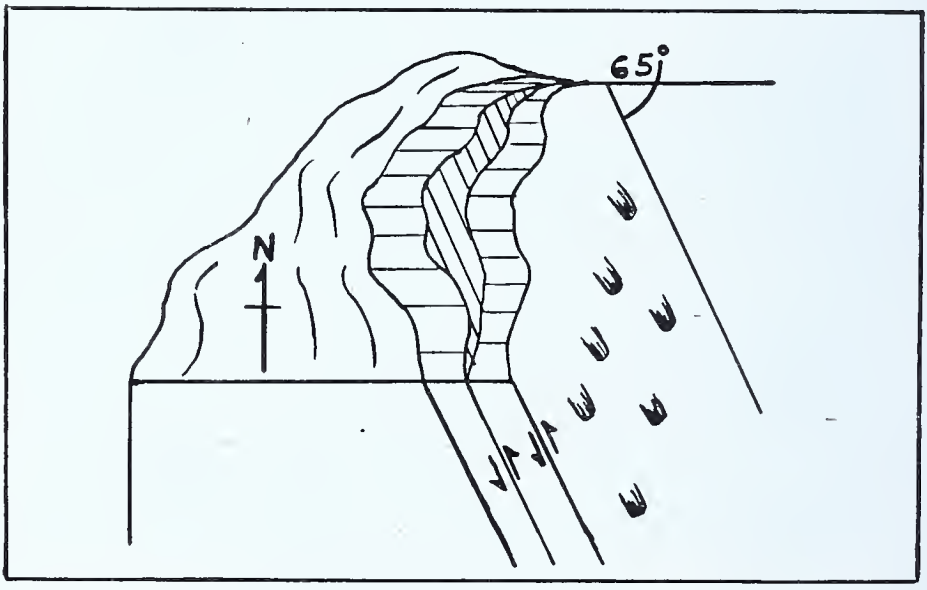

Figure 10. Bedding striae in "ac" plane or bedding of Pocono sandstone, Sherman Valley.

folding and reflects the true direction of rock transport in the local area. Linear structures in the direction of the fold axis are lacking.

Mauch Chunk Formation

General description. The Mauch Chunk formation, also of Mississippian age, disconformably overlies the Pocono sandstone, the Loyalhanna limestone being absent in this region. It is disconformably overlain by the Pottsville sandstone because the top part of the formation was eroded before deposition of the Pottsville. The Mauch Chunk formation is about 1,000 feet thick in this region and under-

lies the valley areas, namely Sherman Valley, the large flat cove around Wells Tannery, and the narrow valley trending almost due north by the borough of Hopewell. Outcrops of the formation are locally abundant and fresh.

Lithologic description. The Mauch Chunk formation consists primarily of soft, red shale. The shale is thin-bedded and finely laminated, locally sandy, and, in the basal 100 feet, limy (pl. 7, B). There are also lenses of grey, crystalline, and red limestone in the basal part of the formation. The lowermost limestone, the so-called Trough Creek member, locally attains a thickness of 25 feet. It is a siliceous, grey, crystalline rock, slightly resembling the Loyalhanna limestone in physical aspect (pl. 27, A). Possibly it represents the Loyalhanna phase of deposition. Occasional beds of the shale are massive and these beds are always sandier.

Approximately 100 feet from the top of the formation is an intraformational conglomerate five feet thick composed of broken and rounded fragments of the shale (pl. 26, A). This bed is persistent enough locally to serve as a key bed. Manganese oxide, chiefly in the form of "psilomelane type" minerals, occurs in the basal part of the formation.

Petrographic description. The shale is finely laminated, the average thickness of the laminae being .1 to .5 millimeters. The grains are mainly anhedral or subhedral and show gradation in size from smallest at the top to largest at the bottom. The size of most grains ranges from .01 to .06 millimeters in diameter.

The most abundant minerals are quartz, sericite, and limonite. The average mode is quartz 40 percent, sericite 35 to 40 percent, and iron oxide 20 to 25 percent.

The quartz is clear, sub-rounded to rounded; some grains are strained, showing undulatory extinction with 2V measurable up to 4 degrees.

The sericite occurs as primary thin fibers and small plates parallel to the lamination planes. A few light-colored laminae are composed entirely of the sericite. However, where it is more abundant and thickly matted, there is usually a greater amount of iron oxide. This relationship is fairly constant; shale containing more sericite also contains more limonite.

Iron oxide is in large part primary, as well shown at one place where the sediments, including a thin lamination of pure iron oxide, suffered contemporaneous deformation (pl. 24, A). For the most part the iron oxide occurs as cementing material surrounding the grains, flakes and fibers of sericite and quartz.

Kaolinized areas of irregular shape, and slightly larger than the normal grains, indicate original feldspar grains now completely altered.

Insignificant amounts of primary zircon and tourmaline occur.

Replacement of basal beds of the Mauch Chunk formation by supergene manganese oxide and iron oxide has been at the expense of primary iron oxide, sericite and, to a lesser extent, quartz.

Structural description. The Mauch Chunk shale has the same regional trend of outcrop as the underlying Pocono sandstone, pre-

viously described. Consequently, its bedding strikes mainly in the two directions represented by the limbs of the plunging synclinal fold, N.65°E. and N.20°E.

Unconformities: There are no angular unconformities; the "breaks" at the top and bottom of the Maueh Chunk are of erosion and cessation of deposition, not tectonic deformation.

Joints: Two sets of joints are developed in the shale throughout the region. Cross joints are the better developed set. Longitudinal joints are locally well developed and, at other places, observed with difficulty. The cross joints, striking nearly at right angles to the bedding, have vertical or very steep dips; the longitudinal joints dip from 30 to 80 degrees in a direction opposite to the dip of the beds. Where the bedding is steep, as on the northwest limb of the large fold, the longitudinal joints have their most gentle dips; where the bedding is gentle, as on the southeast limb of the large fold, the longitudinal joints have their steepest dips The two sets of joints bear an angular relation to each other of 80 to 90 degrees (pl. 5, B). Because the joints are developed in all parts of the large fold, the poles of their planes, as plotted in figure 11, form a girdle arrangement. The

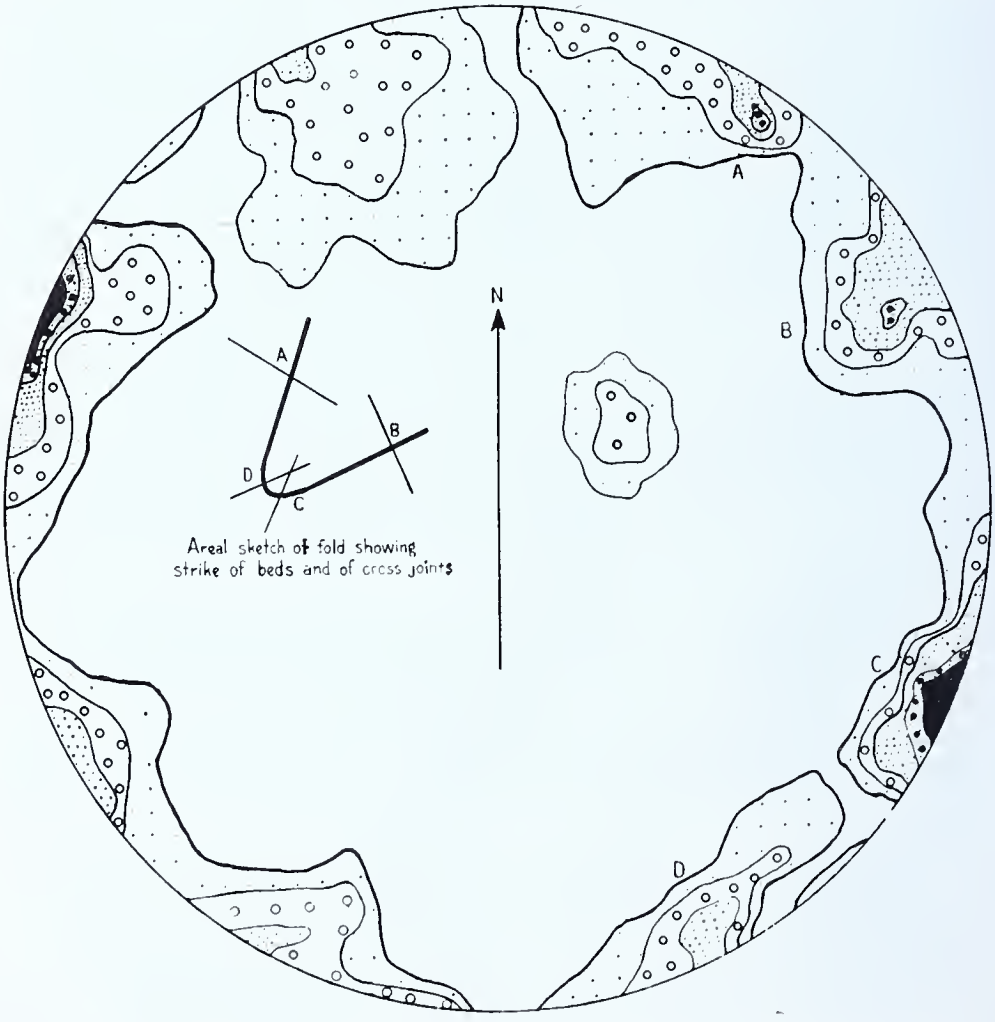

Figure 11. Joints in the Maueh Chunk shale and their relation to the large fold in Sherman Valley. Data based on 970 joint measurements; contoured on ½, 2½, 5, 7½, and 10 percent.

poles of the cross joints are concentrated along the periphery, indicating steeply dipping surfaces, and the poles of the longitudinal joints are scattered inside the periphery, indicating more gently dipping surfaces. The longitudinal joints account for the broad and continuous arrangement of the girdle, while the areas of maxima represent the trend of the cross joints at different positions on the fold. *The strike and dip of the bedding and plunge of the fold has governed the strike of the joints.* (See plate 1 in pocket.)

The trend of cross joints in the Mauch Chunk shale is similar to the trend in the Pocono sandstone. The majority of measurements in the two formations are stratigraphically about 1,500 feet apart. The joints on the northwest limb of the fold, especially, show the same strike and dip in both formations. Most of the joints around the nose of the fold in the Pocono sandstone dip westward 50 to 60 degrees, while the cross joints of the Mauch Chunk shale are nearly vertical. This discrepancy is strikingly shown by comparing the two diagrams in figures 9 and 11. The Pocono sandstone is a competent formation, the Mauch Chunk shale incompetent. The shale has excellently developed joints and cleavage. The sandstone has no obvious cleavage. It appears that the well-developed set of joints in the sandstone which dips westward may be, in part, an expression of the direction of cleavage in the fold. Compare the position of the joints with the diagram that shows cleavage in the shale (fig. 12). There is a close similarity between the joints of the two formations on the southeastern limb of the fold also. However, the lack of exposures of the Pocono sandstone along this limb has prevented the observation of a sufficient number of joints to form a prominent maximum which would correspond to that in the Mauch Chunk shale.

Cleavage: Cleavage is excellently developed in the Mauch Chunk shale at many places. The cleavage is a fracture cleavage and, at the same time, nearly a true axial plane cleavage. The maximum of 115 measurements of cleavage in the Mauch Chunk shale, most of them measured near the nose of the large syncline along the macadam road in Sherman Valley, is N.26°E., 70°W. (fig. 12).

There is some evidence of small variation in the strike of the cleavage planes around the nose of the fold, and it is suggested that detailed work on cleavage in this area would definitely reveal a gentle "fanning" of the cleavage planes. However, figure 11 shows a sharp and definite maximum of cleavages in this area and any variation would be a slight one.

The relation of cleavage to bedding can be observed at many places in the field. Since it approaches true axial plane cleavage, its relationship to the bedding can be used to determine the relative position on the fold. Figure 13 is a sketch of an outcrop near the nose of the large fold in Sherman Valley. The dip of the bedding is 50°E., and that of the cleavage vertical.

The direction of cleavage and of the axial plane of the fold has obviously influenced the position of one set of joints. The strongest set of joints in the shale has a maximum position which is very close to the maximum position of the cleavage. It seems likely that the cleavage direction has influenced both the position of this set of joints and of the more gently dipping set of joints in the underlying,

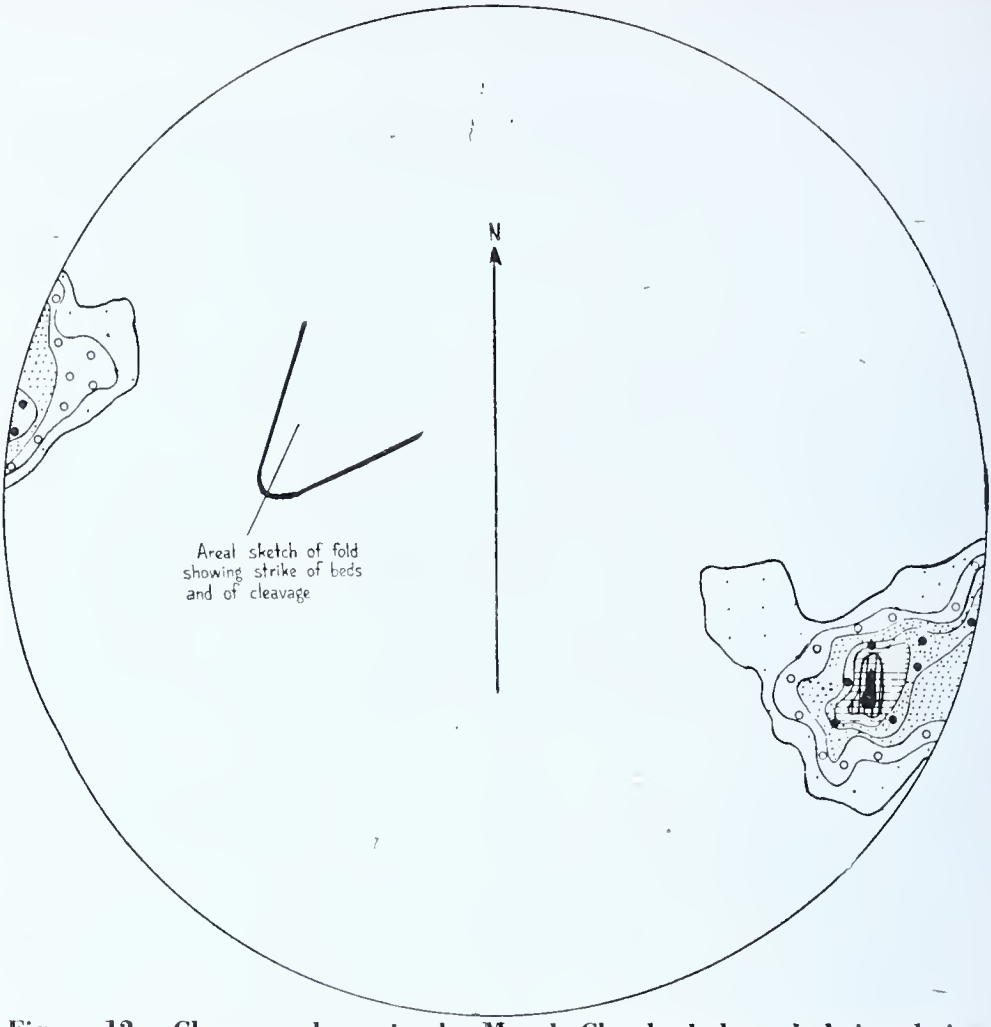

Figure 12. Cleavage planes in the Mauch Chunk shale and their relation to the large fold in Sherman Valley. Data based on 115 cleavage measurements; contoured on 5, 10, 14, 18, 22, 26, and 30 percent.

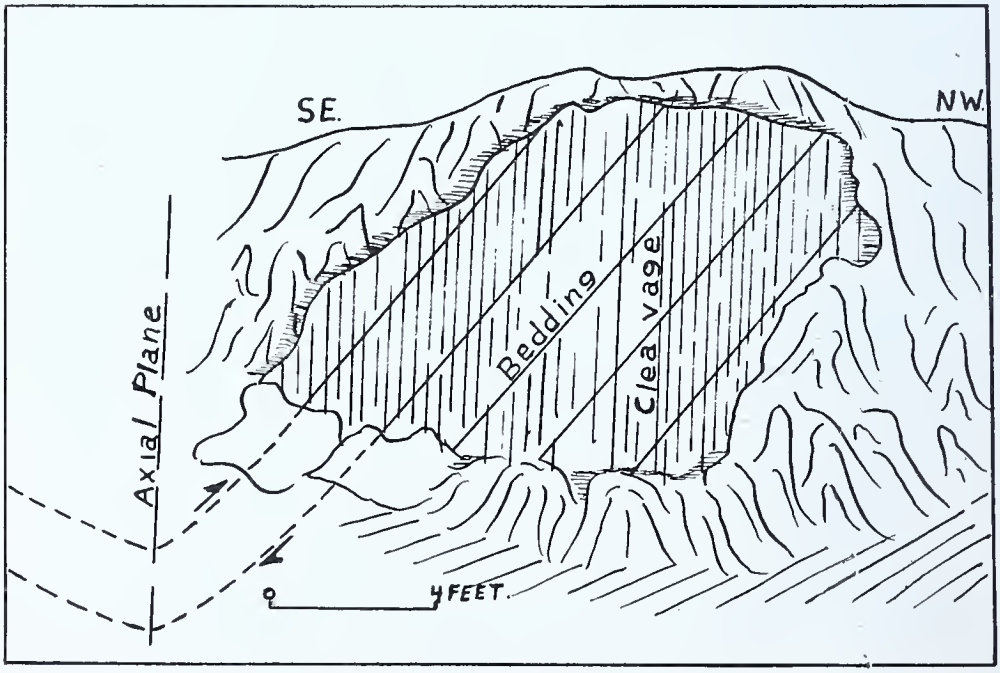

Figure 13. Relation of cleavage to bedding in outcrop of Mauch Chunk shale, southwestern part of Sherman Valley.

competent Pocono sandstone. Comparison of the joints and cleavage in figures 9, 11, and 12 shows this relation well.

In the field the cleavage is best developed on weathered surfaces of the shale. It "stands out" by virtue of weathering along the closely spaced cleavage planes which has broken the shale into thousands of tiny elongated fragments that lie, loosely aligned, on the surface (fig. 14).

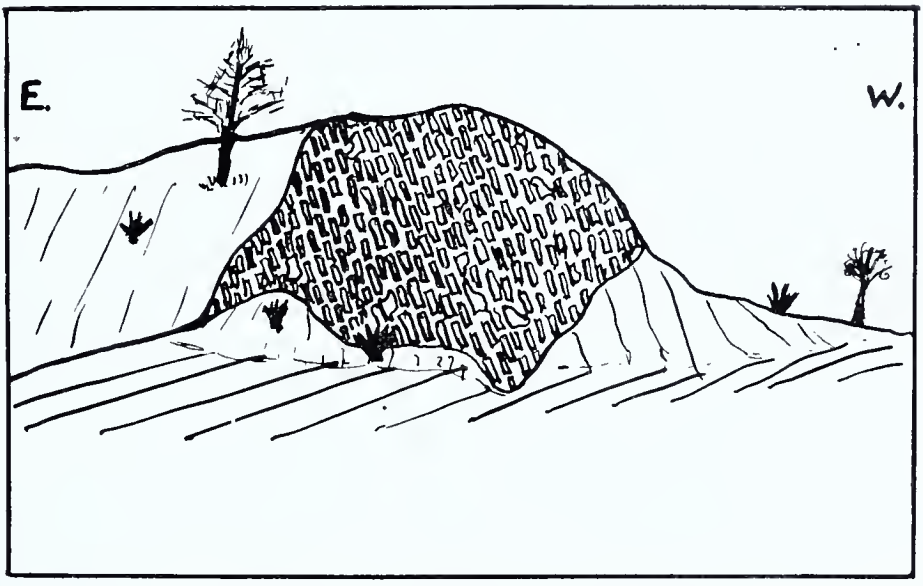

Figure 14. Appearance of cleavage on weathered outcrops of Mauch Chunk shale.

Cleavage is older than any jointing in the shale.

Lineation: Striations on the bedding surfaces of the soft shale are in the direction of folding and at right angles to the fold axis. These striae are numerous and, at some places, are so closely spaced as to form a crudely slickensided surface. They are clearly the result of movement along bedding planes and are classed as lineation in the "ac" plane. They are best developed near the nose of the fold and on the steep-dipping limb.

There is no megascopic evidence of lineation in the B direction, or the direction of the fold axis.

Faults: Two faults were observed in the Mauch Chunk shale, and a number of others may be inferred because of sharply divergent directions of strike.

One and a half miles north of Cypher Station, along the Raystown Branch of the Juniata River (Everett sheet), a small fault cuts the Mauch Chunk shale. It is a normal fault, striking N.80°E. and dipping 80°S. The greatest movement has been in a horizontal direction, with the north side moving westward; horizontal displacement could not be measured. Vertical displacement is 6 feet.

One and a half miles southwest of Cypher Station, on the south side of the macadam road, in the southwestern part of Sherman Valley, a weathered outcrop of red shale is faulted. The fault itself

is obscured, but measurements on beds within five feet of each other bear strikes of N.12°E. and N.25°E. Though the outcrop is badly fractured and much weathered, the divergent strikes are not due to ordinary slumping, or to primary depositional structure in the sediments. The displacement could not be measured.

Cross faults have been mapped at two places in Sherman Valley on the strength of incompatible structural alignment of the Pocono sandstone and Mauch Chunk shale beds. There are probably other cross faults, for all the cross structures in the "ac" plane are strong and well-developed. Displacement along the cross faults is essentially horizontal and its magnitude is probably from 25 to 100 feet in most cases. The cross faults are probably the same age as the cross joints.

PENNSYLVANIAN

Pottsville formation

General description. The topmost sandstone beds of the Pottsville formation disconformably overlie the Mauch Chunk shale in the Sherman Valley area. The top of the Mauch Chunk shale was being eroded while the lower beds of the Pottsville sandstone were being deposited farther to the northwest. The sandstone is about 300 feet thick and floors the Broad Top coal field, cropping out as a steep escarpment at many places along its edge.

Lithologic description. The sandstone is light-grey to tan, massive, and coarse-grained. The lower beds of the Pottsville are shaly; tan and red arenaceous shales are the chief type. Some beds are distinctly conglomeratic.

Allegheny formation

Rocks of the Allegheny formation occur only in the Broad Top coal field and, as such, are not of immediate interest to this report. They consists of tan shales and sandstones and four major coal beds, none averaging more than 4 feet in thickness.

STRUCTURE

RELATION TO REGIONAL STRUCTURE

The Sherman Valley area is part of the Ridge and Valley province of linear folds trending generally northeast-southwest across Pennsylvania. It is situated in the southern part of the Pennsylvania salient,[59] the large northwestward arcuate trend of the Appalachian System in Pennsylvania, and approximately half way between the horizontal beds of the Appalachian Plateau and the highly folded and faulted beds of the Great Valley. Because of its position on this salient, the trend of the folds is N.20°E.

LOCAL STRUCTURE

Details of the local structure[60] have been discussed completely in the structural descriptions of the Pocono and Mauch Chunk formations and reference should be made to these descriptions and to Plate 1.

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[59] Keith, Arthur, Outlines of Appalachian structure; Bull. Geol. Soc. Am., pp. 309-380, 1923.

[60] Foose, R. M., Secondary structures on an asymmetric syncline near Everett, Pennsylvania: Proc. Penna. Acad. Sci., pp. 54-62, vol. 18, 1944.

General features. The Sherman Valley area is an asymmetric syncline which plunges northeast (fig. 15). The axial plane of the fold strikes N.26°E., dips 70°W. Fracture cleavage, which is nearly an axial plane cleavage, is well-developed in the Mauch Chunk shale and also strikes N.26°E., dips 70°W. In the steep northwest limb of the fold, the beds strike N.20°E., dip 50-80°E. On the gentle southeast limb, they strike N.65°E., dip 15-45°W. The plunge of the fold at its nose in the southwestern part of Sherman Valley, measured as the intersection of bedding and cleavage, is 15-20° N.E.

Joints are well developed in the region. The joint system includes a set of longitudinal joints which bear the same strike as the beds and "follow them around" the nose of the fold from one limb to another. These joints dip opposite to the dip of the bedding and approximately at right angles to the bedding. The best developed set is the cross joint set. They strike at about 90 degrees to the strike of the beds and, likewise, "follow around" the nose of the fold, always bearing the same general relation to bedding. These joints have essentially vertical dips cut directly across both the Pocono and Mauch Chunk formations. On the nose of the fold these cross joints are not vertical in the Pocono sandstone; they dip from 50° to 60°W. (fig. 9). This anomalous dip of the joints may be an expression of the cleavage which has a similar strike and dip where it is well developed in the overlying shale.

Observed and measurable faults are a reverse fault in the Pocono sandstone and a normal cross fault in the Mauch Chunk shale. The occurrence of other cross faults of small displacement is inferred.

Ore Deposits

General Features

Manganese ore occurs chiefly as a replacement of the shale beds in the basal 50 feet of the Mauch Chunk formation. The areal geology in the immediate vicinity of the Sherman Valley open cut is shown in figure 16.

In the Sherman Valley open cut (pls. 3, 4, and 5) are two main "beds," both essentially parallel with the bedding of the shale, and dipping 15°-20°NW.

The ore beds are separated by 15 feet of shale which is stained black by films of manganese oxide on joint and bedding surfaces.

Small stringers of oxide, less than one-quarter inch thick, occupy some of the joints. The lower ore bed averages 4 feet and ranges from 3 to 6 feet in thickness (fig. 17 and pl. 4, B). It is dark brown to black, blocky manganiferous iron ore with an average manganese content of 10 percent (pl. 8, B).[61] The upper bed averages one foot and ranges from one-half inch to 3 feet in thickness. It is not nearly as uniform in thickness as the lower bed and swells and pinches, cutting across the bedding of the shale where it thickens. It is hard, steel-blue manganese ore with a minimum average manganese content of 40 percent (pl. 9, A). Many analyses show 50 percent and more of manganese.

[61] Figure based on analyses of shipments of run-of-mine ore.

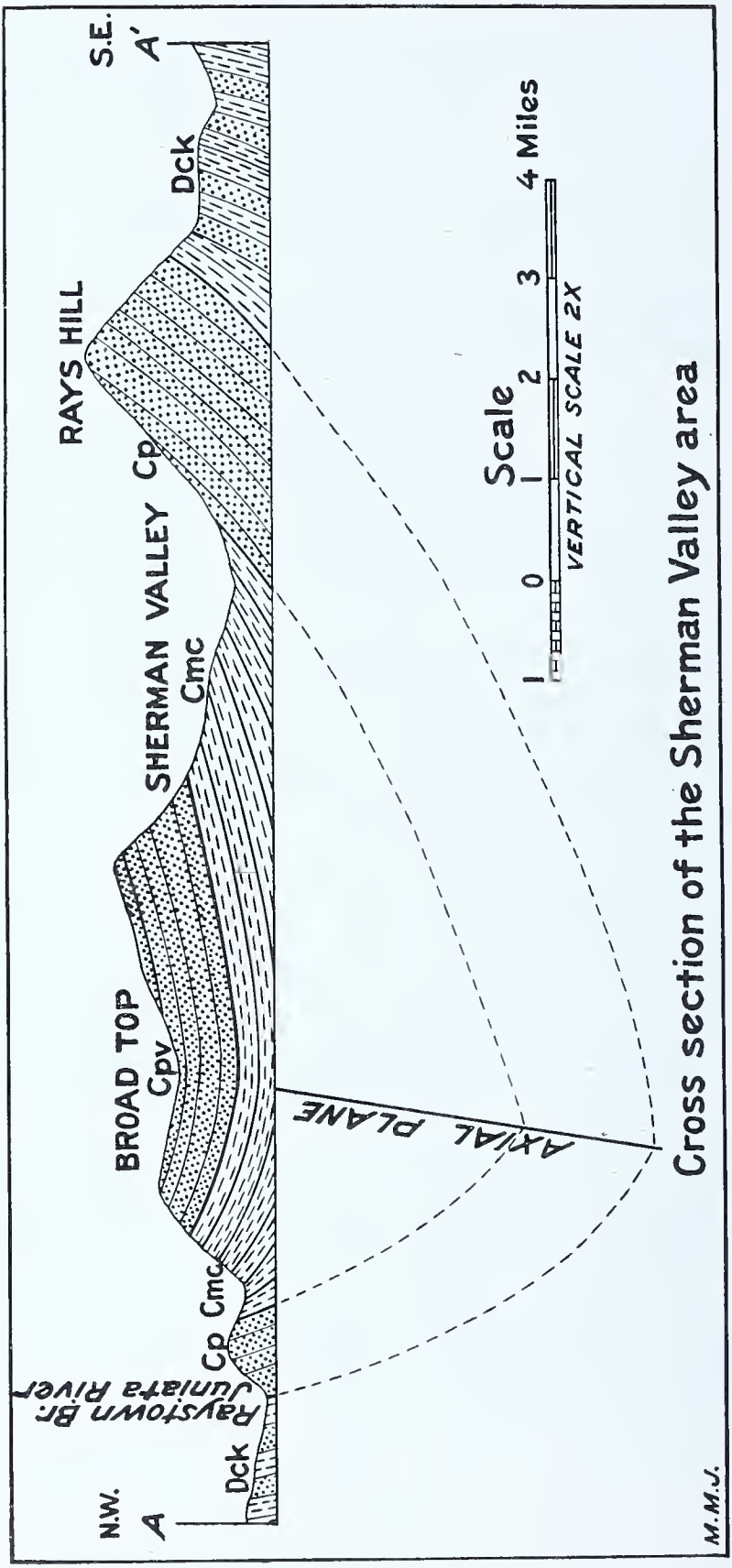


Figure 15. Cross section of the Sherman Valley area.

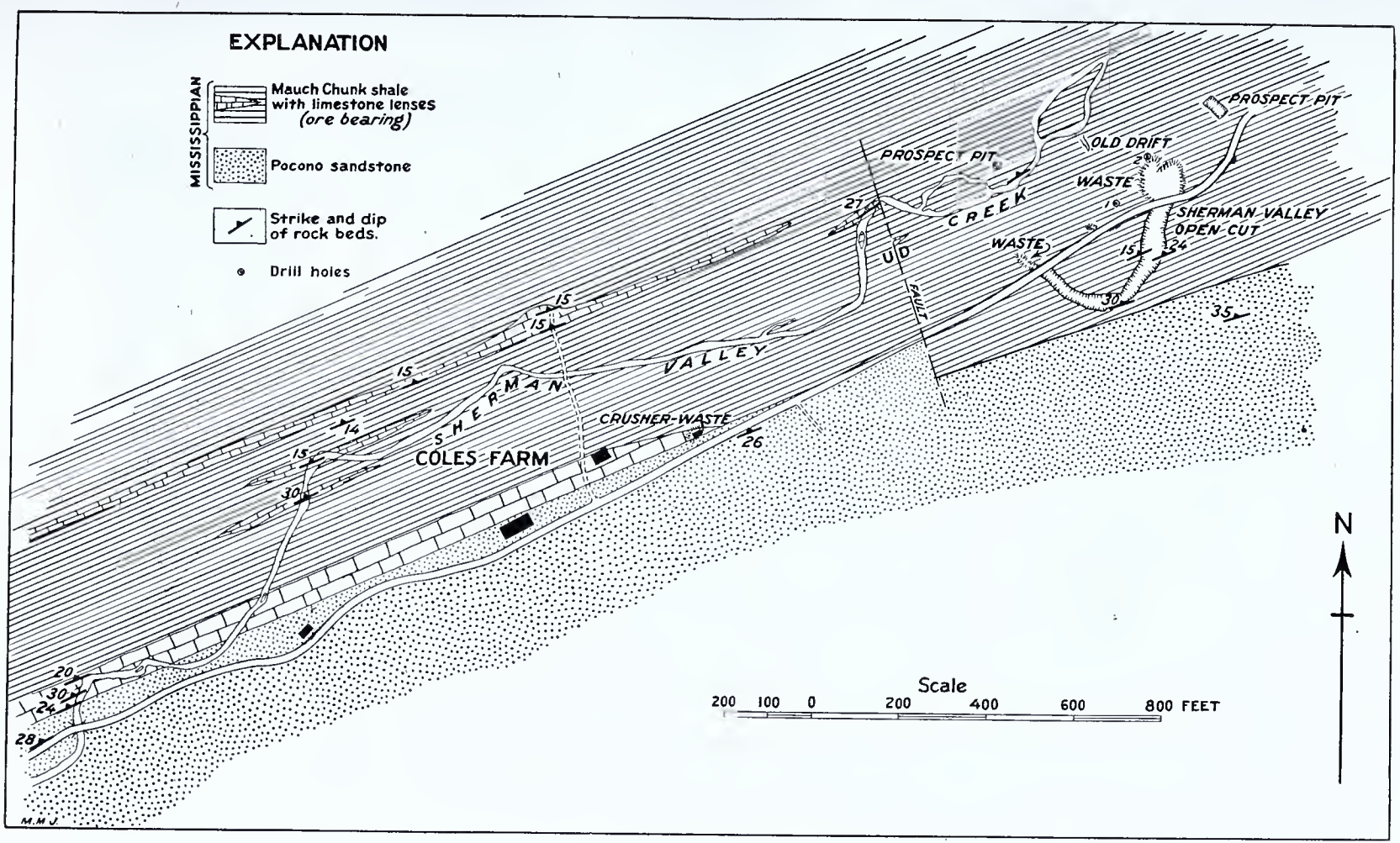


Figure 16. Geologic map of Sherman Valley open cut and the immediate vicinity.

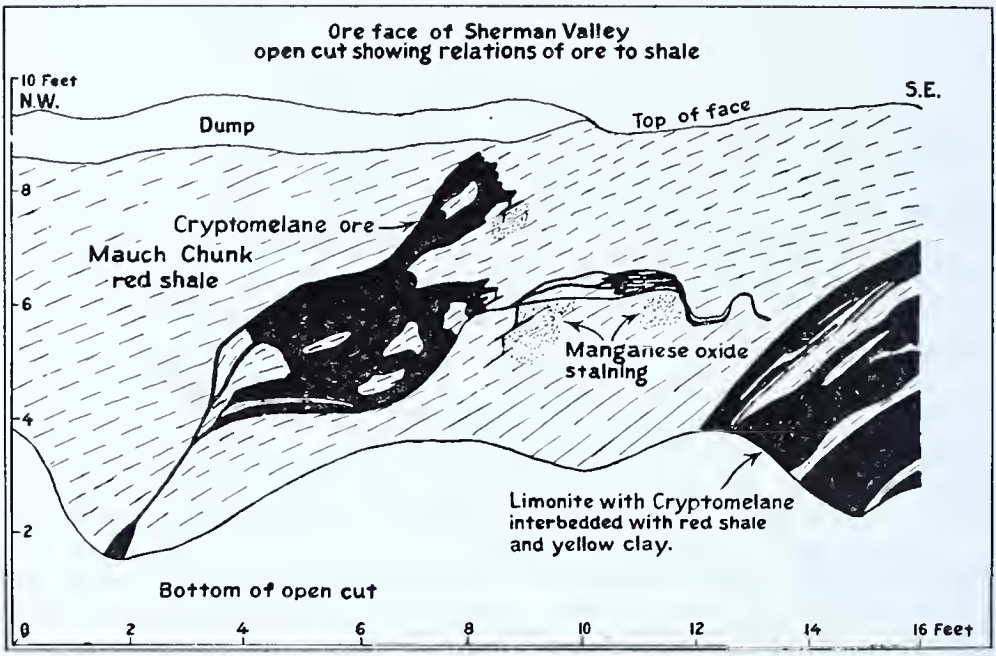


Figure 17. Ore face of Sherman Valley open cut showing relation of ore to shale.

A 70-foot slope from the floor of the open cut is in the lower bed of ore. The slope is slightly more than 6 feet high and most of it lies in ore. Figure 18 shows the character of the ore in the wall of the slope.

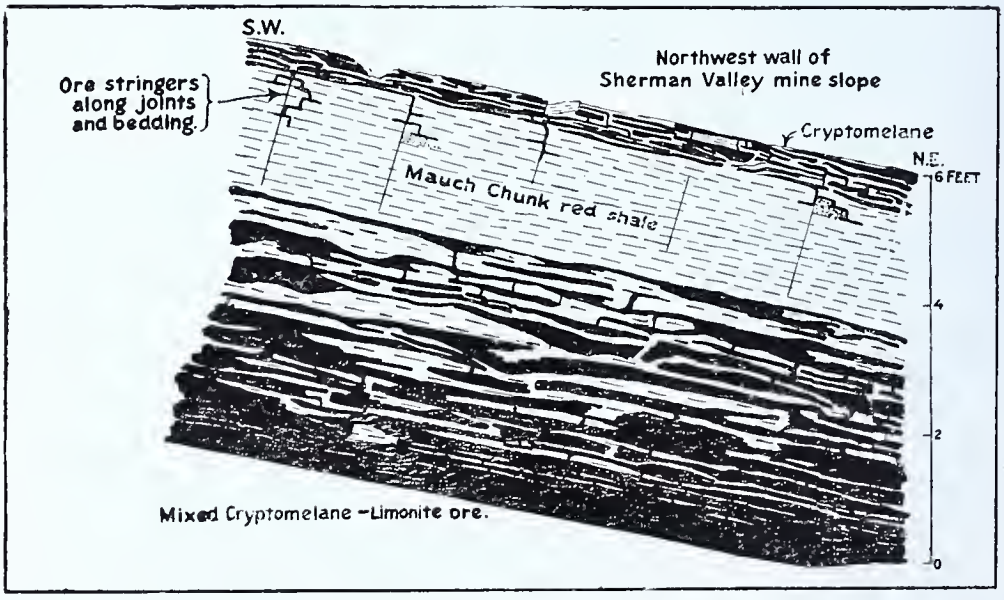


Figure 18. Relation of ore to shale in northeast wall of Sherman Valley mine slope.

Mineralogy

Ore minerals. The ore minerals are oxides of iron and manganese. The chief manganese mineral is cryptomelane. It is typically dense and steel-blue, has a sub-metallic luster, a hardness of 6 to 7, a sub-conchoidal fracture, a black streak with a brownish tinge, and a specific gravity of 4.28.[62] Common to the mineral are small bands in which tiny prismatic or needle-like markings of silver color and brilliant metallic luster "stand out"; this is called "silver grain." These physical properties are similar to those of psilomelane. However, the mineral contains 3 to 4 percent of K_2O and practically no BaO. The lack of BaO, common to true psilomelane, and the presence of K_2O, uncommon to true psilomelane, distinguish cryptomelane from psilomelane.

The molecular structure, as interpreted from X-ray powder photographs, also differs from that of true psilomelane. This distinction is critical and adequate for classifying the mineral as cryptomelane.

Microchemical tests and etching tests on cryptomelane from Sherman Valley do not show any diagnostic criteria by which it may be distinguished from true psilomelane, nor are the tests constant on cryptomelane itself. The influence of physical properties, such as grain size and water content, are obviously part of the reason for this.

The ore of cryptomelane takes several forms. It may be completely bedded and massive, or individual beds, averaging two inches in thickness, may be "split" in the middle with botryoidal growths approaching each other from top and bottom. Most of the botryoids are very minute; they range up to one-quarter inch in diameter. There is no measurable difference in size between the botryoids on the top and bottom. There are all gradations between solid, massive beds with obscured botryoidal structures and opened, or split, beds with prominent irregular botryoidal surfaces. The central portion of some of the dense beds of cryptomelane is softer and black. These zones, usually one-half to one inch thick, are alteration zones consisting of pyrolusite (MnO_2).

Thin stringers of cryptomelane, iron oxide, and soft, black manganese oxide occupy some of the joint planes in the shale. The shale between the two ore beds is cut up by these stringers; several extend from one ore bed to the other.

In addition to cryptomelane and the pyrolusite in the center of altered ore beds, the manganese oxide minerals include wad. It occurs as a few small masses in the residual mantle overlying the red shale and as small stringers and films of oxide which fill and cover joint and bedding planes in the shale. It is clearly later than cryptomelane.

The iron oxide is of two types. Primary iron oxide in the Mauch Chunk shale (S.V.-9B) is deep red-brown and occurs as thin laminae, .01 mm. or less thick, and as cementing material in the shale. Secondary iron oxide, which is abundant in the lower ore bed, is brown in color and has replaced sericite, primary limonite, and some of the quartz.

[62] Homogeneous sample, determined by Jolly balance.

Gangue minerals. The most abundant gangue mineral is quartz, which is the mineral of the host rock most resistant to replacement. It is sub-rounded and clear. Less abundant gangue minerals are sericite, carbonate, calcite, orthoclase, kaolinite, and a few scattered grains of zircon and primary rounded grains of chalcopyrite, which is very strangely associated with the shale.

Gangue consists for the most part of unreplaced masses of red shale.

Structures and textures. Colloform texture is strikingly developed both in dense and massive cryptomelane and in the botryoidal type (pls. 20, B and 21, A), but not in the iron oxide of the lower ore bed. The texture indicates rhythmic deposition of manganese oxide, probably in a gel-like medium. The shale has been replaced along the surface of growing botryoids which embayed it. The thin colloform bands of the manganese oxide vary slightly in physical character, and probably in chemical character, as would be expected of material deposited from solutions which are constantly changing. The different nature of the colloform layers has made some of them more readily replaceable. A second generation of cryptomelane has replaced them (pl. 20, B) and, in addition, formed growth caps on the first generation cryptomelane (pl. 21, A).

Another textural type created by the second generation of cryptomelane is a needle-like or splintery texture (H-6), around irregularly resorbed areas of first generation cryptomelane, aligned with linear directions always pointing toward the center of the irregular area. Sometimes it clearly cuts the primary generation oxide (fig. 19).

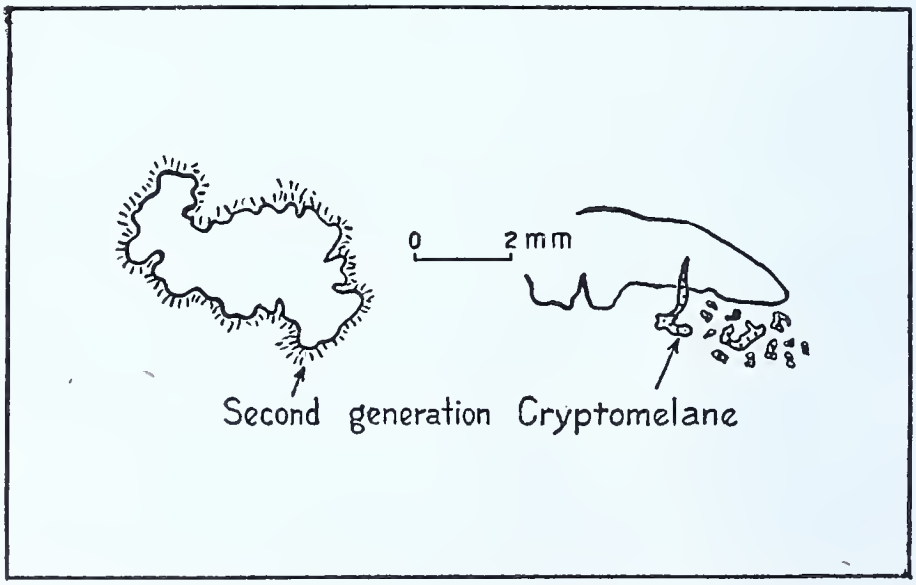


Figure 19. Needle-like growths of second generation crytomelane. This corresponds to Schneiderhohn's "Gemengteil Nr. 2" (component No. 2) of psilomelane.[63]

[63] Schneiderhohn, Hans, and Ramdohr, Paul, Lehrbuch der erzmikroskopie, p. 516, Borntraeger, Berlin, 1931.

Replacement of the arenaceous shale produced the most common texture. Irregular patterns are formed by unreplaced, sub-rounded quartz grains imbedded in the manganese oxide. At some places the quartz is partly replaced and surrounded by iron oxide which, in turn, is replaced by veins of cryptomelane. A varied and heterogeneous texture results, though always controlled by the bedding. H-4 and other descriptions show these variations.

Paragenesis. The mineral sequence in the Sherman Valley area, based mainly on microscopic study of ore from the Sherman Valley open cut, is (pls. 20, 21, 22 and 23):

1. Primary bedded red shale, consisting mainly of quartz, sericite, and primary limonite, and containing orthoclase, kaolin, zircon, and chalcopyrite.
2. Limonite.
3. Cryptomelane. Practically contemporaneous with 2.
4. Second generation cryptomelane.
5. Pyrolusite—alteration by primary solutions.
6. Soft black oxides (wad)—surficial weathering.

The paragenesis of the minerals is clean-cut except for limonite and first generation cryptomelane. These two are practically contemporaneous, as indicated by conflicting age relations in ores physically near each other.

Second generation cryptomelane is not nearly as abundant as that of the first generation and as limonite. Because both generations of cryptomelane are almost identical physically and have nearly the same optical properties, one cannot be sure that second generation cryptomelane has formed only by replacement of first generation cryptomelane and that it has not also replaced shale.

The occurrence of pyrolusite in the center of densely bedded ore indicates late alteration by the solutions which carried the earlier manganese oxides rather than much later alteration by normal weathering processes. This is in contrast to the later formation of soft black oxides of manganese (conveniently called wad) by normal processes of weathering.

Chemical Composition of the Ore

Table 8 includes 25 analyses of ore from the Sherman Valley workings. Samples marked "lump" or "washed sample" are selected and represent the composition of ore which might be approached by selective mining. Samples marked "R.R. car," "channel sample," or "stock pile" represent run-of-mine ore.

The manganese content of selectively mined ore averages well above 35 percent. The manganese content of run-of-mine ore is fairly constantly about 10 percent, which is sufficiently high for the production of spiegeleisen. The iron content of the high-grade ore is not objectionable; neither is it objectionable in the low grade ore for the production of spiegeleisen or electrolytic manganese.

The silica content is locally high, but the average is not high enough to make the ore unsalable. Though the phosphorus content

is locally high the average is low enough that the ore may be handled by modern metallurgical treatment.

Genesis

Nothing definite can be stated concerning the ultimate source of the manganese in the ore minerals other than the fact that it is of supergene origin and from a source stratigraphically higher than the ore-bearing beds.

The manganese and iron oxides are both typical of surficial mineralization, and it seems likely that the minerals were never formed at a depth of more than several hundred feet. Likewise, the ore-bearing solutions, which were probably percolating waters, were not hot; they may have been slightly warm at the greatest depths.

Structural control by bedding and compositional control by the minerals of the shale governed the replacement processes. The solutions moved down the dip of the beds near the contact of the Mauch Chunk shale with the Pocono sandstone and, to a much lesser extent,

Table 8. Analyses of the Sherman Valley Ore (in percent)

Character of sample	Mn	Fe	SiO_2	P	Moist.	Analyst
lump	32.12	8.20	27.20	0.166	—	*
do	35.71	1.40	31.80	0.142	—	*
do	37.01	2.00	28.50	0.112	—	*
do	44.46	1.65	17.09	0.24	—	†
Washed lump ore	39.10	9.85	—	—	—	†
" crushed ore	50.71	1.40	1.90	0.25	—	†
lump	54.96	0.67	1.18	0.27	—	†
washed crushed ore	55.10	0.39	0.33	0.27	—	†
lump	50.43	3.13	5.09	0.32	—	†
do	42.09	7.06	9.48	0.27	—	†
do	40.35	—	—	0.28	—	†
channel sample	31.47	1.88	35.94	0.21	—	†
do	40.92	1.73	23.28	0.22	—	†
do	52.06	0.67	4.82	0.31	—	†
do	16.94	1.45	46.88	0.09	—	†
R.R. car (top)	7.83	34.11	—	—	—	‡
do (bottom)	6.19	37.75	—	—	—	‡
do (top)	13.11	24.0	—	—	—	‡
do (bottom)	15.90	23.50	—	—	—	‡
do	9.72	33.1	—	—	—	‡
Stock pile	12.60	23.0	—	—	8.0	‡
R.R. car	12.21	21.80	—	—	—	‡
do	12.57	25.47	—	—	—	‡
do	10.90	25.28	—	—	3.5	*
do	21.49	16.07	—	—	—	*

* Alan Wood Steel Co.; † E. J. Lavino Co.; ‡Riddlesburg Coal & Iron.

across the bedding along joints. The manganese was most likely in the soluble form of the carbonate or bicarbonate. Sericite, primary limonite and, to a much lesser extent, the quartz of the shale were replaced by manganese oxide (cryptomelane). Solution of the shale evidently proceeded faster at some places than replacement, as shown by the "split" ore, in which the shale is absent from the middle opening and botryoidal clusters have partly grown toward each other by precipitation from solutions that migrated through the channel.

The channel-like path of the solutions, at least during later stages of the ore formation, is also clearly shown by alteration of massive beds, in the central channel zone, to pyrolusite (pl. 21, B).

The composition of the solutions evidently changed during the processes of replacement and deposition and the change affected the ratio of the iron-manganese content especially. Why the manganese-rich ore lies above the iron-rich ore, when the solubility of manganese is greater and most occurrences are of the opposite nature, is not clear.

The time of formation of the ore can only be surmised. The probable fact that the ore formed at shallow depth and the knowledge that this area was peneplaned in Tertiary time, thus removing great thicknesses of overlying rocks and possibly also serving to concentrate the manganese and iron oxides residually in the weathered zone of the peneplaned surface, suggests a middle or late Tertiary time. Continued accumulation, and partial alteration, of the ore in Recent time is probable.

Ore Dressing

Some of the finer crushed ore from the Sherman Valley open cut was collected, carefully washed, briquetted in a thermoreactive plastic, and ground and polished in a plane cross-section.[64] The coarser material, ranging between .05 and 1 mm. diameter, was studied in vertically reflected light. This material is composed of equal amounts of free manganese oxide grains (cryptomelane) and grains of manganese oxide intimately mixed with limonite and quartz grains which range from 005 to .13 mm. in size.

The purpose of studying washed ore in this way was to determine the possibility of dressing the ore in some manner which would increase the percent of manganese. The ore, as mined, including both grades of ore, contains about 20 to 30 percent of manganese as an average. The low grade ore, of course, could be easily separated by hand in the open cut or at the crusher. Washing the ore removes much adhering clay, weathered shale, and smaller pieces of limonite, as well as small pieces of cryptomelane, and increases the manganese content to 35 to 40 percent of manganese. The writer wished to determine the feasibility of increasing the manganese content to 45 and 50 percent. The limonite and quartz are so intimately mixed with the manganese oxide in the impure grains that exceedingly fine crushing would be required to liberate more than 50 percent of the impurities. At least 50 percent of the limonite and quartz together average 200 to 300 mesh in size (pl. 23). Thus, crushing to 200 mesh would liberate half, or more than half, of the gangue and increase the manganese content of the high grade ore concentrate. Much of the gangue material, especially the limonite, is not so easily separable.

Five analyses of high grade ore from the Sherman Valley open cut were selected to represent the maximum percentage of manganese recoverable under optimum mining and milling conditions. The five analyses and their average are given here in percent.[65]

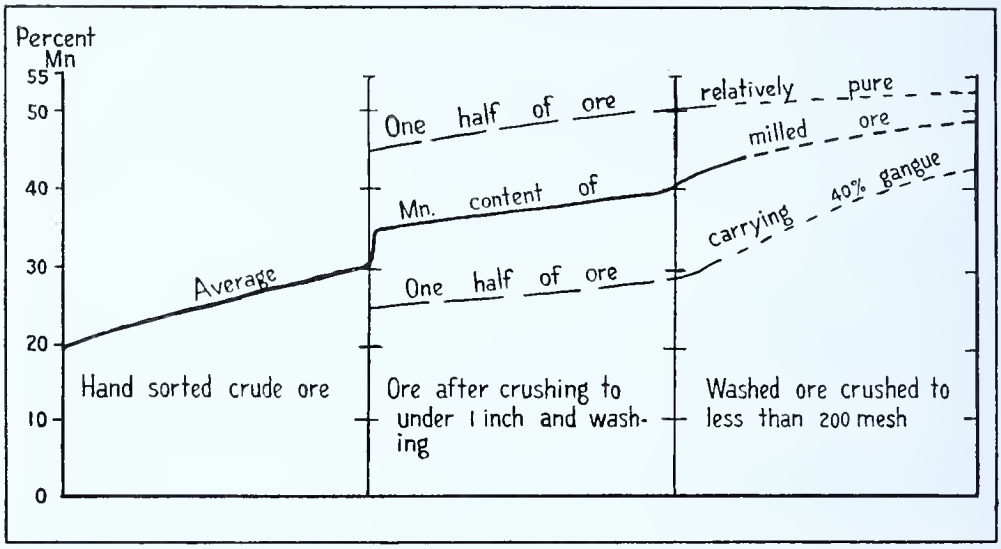
[64] The briquettes and polished faces were prepared by the American Cyanamid Company.

[65] The average manganese content of cryptomelane is about 55 to 60 percent. The predominant ore mineral in the Sherman Valley open cut is cryptomelane.

Analyses of Manganese Ore from Sherman Valley

	Mn	Fe	P	SiO_2
1.	54.96	0.67	0.27	1.18
2.	55.10	0.39	0.27	0.33
3.	50.71	1.40	0.25	1.90
4.	57.34	1.80	—	.18
5.	44.46	1.65	0.24	17.09
Ave.	52.51	1.18	0.25	4.14

Figure 20 shows diagrammatically the results of increased milling



N.B. Dashed lines are interpolated and not confirmed by ore dressing experimentation. Fineness of crushing may cause decrease in recoverable manganese.

Figure 20. Diagrammatic sketch showing increase of manganese content by washing and crushing.

of the ore. The average content of manganese increases from 20 to 30 percent to 35 to 40 percent by washing and crushing to one-inch size. The average content can be increased to 45 to 50 percent after grinding to 200 mesh by the removal of limonite and quartz gangue. Microscopic examination of the washed ore in polished section shows that about 50 percent of the manganese oxide grains contain approximately 40 percent of gangue intimately locked in the grains, or a total of 20 percent of gangue material. Careful measurement of the gangue sizes revealed that more than 50 percent of the gangue could be freed and eliminated if all the material were crushed to 200 mesh. Thus, a total of 10 percent of gangue could be gotten rid of, thereby increasing the manganese content 10 percent. This would yield a concentrate of 47 or 48 percent of manganese oxide. Satisfactory separation of the manganese oxide and the quartz might be made by some milling process. No concentration tests were conducted in connection with this investigation Such fine grinding and subsequent milling may result in prohibitive manganese oxide losses. Whether that would happen or not can only be determined by detailed ore-dressing experiments.

Economics

On the basis of exposed ore on the property, both in the drift of 1919 and the open cut of 1940, there is a minimum of 100 tons of high grade ore and 1,300 tons of 10 percent ore which can be recovered. On the dumps from the open cut of 1940 there are nearly 100 tons of 30 percent ore which can also be recovered. The exploration by drilling during late 1942 had no value as far as outlining a possible ore deposit and thereby proving tonnages. Making a bald assumption that an average thickness of 2 feet of ore extends 200 feet along the strike and 300 feet down the dip, there is approximately 12,000 tons of ore of good grade that could be proved by a small amount of sound exploration.

A churn drill would indicate an ore-bearing horizon and its approximate thickness; however, some kind of core drill (preferably a diamond drill) would yield much more information concerning the ore. The first drilling should be directly down the dip from the ore face in the open cut and along the strike at intervals of not more than 75 to 100 feet. If the results were favorable, additional drilling could profitably be done at smaller intervals.

Transportation, water supply and drainage, and market conditions are all favorable enough to warrant some additional exploration on this property.

Other areas in Sherman Valley

Manganese oxide ore, including cryptomelane, pyrolusite, and wad, has been observed as float at other places in Sherman Valley, all of them near the contact of the Mauch Chunk and Pocono formations. These areas are indicated on the map of the area (in pocket).

Half a mile east of Cypher Station, near the gap in Rays Hill, through which Sherman Valley Creek flows westward, is an old caved opening with considerable dump material around the portal. These workings are reported to have last been operated about 1900.[66] No ore is visible on the dumps and it is reported that very little ore was ever found.

One and a half miles northeast of the Sherman Valley open cut, on the Dodson property, a 12-foot drift was driven southward into the steep bank, 20 feet below the macadam road. The section measured inside the drift is:

	Inches
Red shale roof	
Red and yellow mottled plastic clay and thin, hard yellow shale	12
Laminated black and yellow sandy clay	8
Deep maroon sandy clay with yellow partings	7
Soft, thin yellow and red shale and clay	4
Homogeneous, unlaminated, black, sandy clay with several yellow sandy partings	19

The black sandy clay contains up to 3 percent of manganese as soft, intimately mixed manganese oxide. The occurrence of the thin beds is so uniform that it is difficult to explain the occurrence of manganese in this form by supergene concentration. This may be primary, sedimentary manganese oxide. Occurrences like this in the Mauch

[66] Mellott, C. P., Sherman Valley, personal communication, August 1941.

Chunk shale would be adequate source for the manganese in the ore of the basal beds.

Above this drift, at an elevation of 1,300 feet, a 12-foot shaft was sunk in 1940. It penetrated only red shale, though float manganese ore is on much of the immediately surrounding area.

Manganese oxide ore has been reported from other places in Sherman Valley,[67] as in the valley of Oregon Creek near Big Wood Ridge, in Duvall Cove, and near Beaverdam Pond in Fulton County. Float manganese ore abounds in all these areas.

The valleys of Oregon Creek and of the small creek that drains Duvall Cove west of Duvall Ridge are structural depressions which "hold" remnants of the lowermost beds of the Mauch Chunk shale and are floored by the competent Pocono sandstone (pl. 1). These valleys have ideal structural conditions for the accumulation of supergene oxide ore. Because there are only remnants of the shale remaining, it is unlikely that any large deposits of ore could be found there. However, for determining that possibility, limited exploration may be considered worthwhile.

READING BANKS

Location and General Description

Manganese and iron ore deposits are located at Reading Banks and in the vicinity of White Rocks,[68] two miles southeast of Boiling Springs, along the northern flank of South Mountain, in Cumberland County. Most of the property is under lease to the Philadelphia & Reading Coal & Iron Company of Philadelphia. The old pits are accessible from Boiling Springs by gravel and dirt roads, and the vicinity of White Rocks is accessible by an old dirt road almost impassable through disuse.

History of Mining and Production

Several small pits were dug in the vicinity of Reading Banks more than a century ago. Residents of Boiling Springs report that ore was mined as long ago as the Revolutionary War. Lesley[69] described small abandoned operations in 1873. At that time approximately 2,000 tons of ore had been removed. Most of it was smelted at the Boiling Springs Furnace and is reported to have been very satisfactory.

In 1872 the Philadelphia & Reading Coal & Iron Company began two large operations on the site of these older banks approximately one mile apart. For about 20 years, they mined ore. Both open cut and underground mining methods were used. The western open cut (old Ege Bank) is about 1,000 x 300 x 80 feet. (See plate 2 in pocket.) The eastern pit (old Beltzhoover Bank) was a little smaller, but it is slumped and filled with water. At the western ore body, two drifts and one slope were driven southward at elevations of about 540 and 560 feet toward the open cut. All of these have caved. The

[67] Stevenson, J. J., The Geology of Bedford and Fulton Counties: Penna. 2nd Geol. Survey, T 2, pp. 222-267, 316, 1882.

[68] Foose, R. M., Iron-manganese ore deposit at White Rocks, Cumberland Co., Penna.: Penna. Geol. Survey Bull. M 26, 1945.

[69] Lesley, J. P., Iron ores of the Cumberland Valley: Occasional Surveys, pp. 6, 7, McCalla & Stavely, Phila., 1874.

two drifts were in ore and intersected the open cut in the middle and at its eastern end. It is reported that the slope, with a grade of 14½ feet in 100 feet, also intersected the middle of the open cut. This seems unlikely, if the grade were constant, for the slope would be at least 20 feet beneath the floor of the cut, and no trace of it can be seen. About 700,000 tons of ore were taken from the open cut and underground operations. At least some of this was smelted at Boiling Springs. Smelting difficulties were experienced and much of the resulting pig iron was cold short and brittle. It was not realized at the time that cold short pig is caused by manganese. Since much of the ore contained a high percentage of manganese, this difficulty finally led to the cessation of operations. Between 1900 and 1910 a drift was driven southeast into the ore exposed on the floor of the open cut at its eastern end. The drift is caved and its length and character are unknown. Some ore may have been shipped at that time.

The large eastern bank is filled with water and has never been worked since it was abandoned by the Philadelphia & Reading Coal & Iron Company about 1893.

In the fall of 1939, the firm of Leghorn and Mitchell, of Boston, Mass., began prospecting in the vicinity of Boiling Springs for manganese ore. Numerous test pits and trenches were dug; many of them showed nodular ore of good grade, and a few showed a sufficient quantity to warrant further exploration. Early in 1940, 3,200 acres of land were leased by that firm, including the land at Reading Banks and White Rocks, and several tracts farther west toward Mount Holly Springs. Stripping operations began at Reading Banks (Ege Bank) in May, 1940, and continued till the end of November. About 1,500 tons of manganiferous iron ore were removed to a stock pile and 3 carloads of ore were shipped to a smelter in September and November. A large steam shovel and, later, a drag line were used to move the clay and ore, which was trucked to dumps and stock piles.

In January-February, 1943, the U. S. Bureau of Mines drilled two churn drill holes, one of them in the pit and the other at the edge of the pit, as part of the larger exploration for manganese ore being conducted in the vicinity of White Rocks, a mile east. Both of these holes indicated the presence of some ore minerals in clay to depths of about 80 feet below the bottom of the pit.

Since 1943 there has been no activity.

General Geology

Physiography

This area is situated at the boundary of two physiographic provinces, the northern section of the Blue Ridge province and the middle section of the Ridge and Valley province. The crystalline rocks of South Mountain are partly overlain along the flanks of the mountain by gently dipping quartzite and limestone beds which extend northward under the Cumberland Valley, part of the Great Valley of Pennsylvania. South Mountain has a fairly even crest at an elevation of 1,400 feet and the nearly accordant low hills of the

Cumberland Valley average 550 to 600 feet elevation. This is the level of an old erosion surface,[70] which also finds local expression on the flanks of South Mountain as a small terrace or bench. The maximum relief in the immediately surrounding area is 1,000 feet; the average is 800 feet.

The main stream of the area is Yellow Breeches Creek, which flows eastward through the Great Valley, one mile north of South Mountain. The drainage pattern is dendritic in the valley and is a combined dendritic and radial pattern on South Mountain.

Stratigraphic Succession

The rocks of the area belong to two large groups. Pre-Cambrian crystalline rocks of igneous origin comprise the core of South Mountain. Lower Paleozoic quartzites and limestones partly overlie the older crystalline rocks along the flanks of the mountain and floor the Great Valley to the north.

In the order of stratigraphic sequence, the Weverton sandstone (Loudon formation), Montalto quartzite, Antietam quartzite, Tomstown dolomite and Waynesboro formation unconformably overlie the pre-Cambrian rocks. The first three members of this group form a series of quartzitic beds more than 3,000 feet thick. The Tomstown dolomite and the sandy Waynesboro formation, having a thickness of about 1,000 feet, are overlain by the great series of Upper Cambrian and Ordovician limestones more than 4,000 feet thick.

The Antietam and Tomstown formations, both of Cambrian age, are the rocks with which manganese ore is associated.

Antietam sandstone. The Antietam sandstone or quartzite is the youngest (topmost) mountain-making formation of South Mountain. It is a relatively pure, hard, coarse-grained, white and grey, quartzitic sandstone (pl. 19, B), bearing numerous scolithus tubes, and weathering, especially in its upper part, to a cream and buff sand suitable for building purposes. Locally it is a vitreous quartzite. The upper part locally carries manganese oxide ore. Exposures of the rock are poor, and it is impossible to measure the thickness of the formation. A general estimate of its thickness in this area is about 600 feet.

The Antietam is a strong ridge maker and underlies the whole northern flank of South Mountain. Large talus blocks, roughly rectangular, cover part of the slope of the mountain and obscure outcrops.

Tomstown dolomite. The Tomstown dolomite overlies the Antietam sandstone. It consists of a lower part of coarse grey dolomite with interbedded siliceous sericitic shale, a middle part of interbedded dark-blue limestone and thin shale, and a top part of purer grey and blue dolomite and limestone with fewer shaly beds. There are no outcrops of the formation in the immediate vicinity. It is covered by a heavy mantle of residual soil and clay. The clay is especially well developed in the basal part of the formation where it is very shaly, and it is this part that bears the manganese ore.

[70] Campbell, M. R., Chambersburg peneplain in the piedmont of Maryland and Pennsylvania: Geol. Soc. Am. Bull. 44, pp. 553-573, 1933.

Structure

South Mountain is an anticline that plunges along its axis toward the northeast and disappears under the lower Paleozoic limestones and shales of the Cumberland Valley. The strike of the mountain and of all the formations which flank it is N.62°E. Its northern flank is folded at several places so that the Cambrian formations form several sharp reentrants along the trend. One of these is at White Rocks,[71] one mile east of Reading Banks. These reentrants are both structural and topographic. In addition to this subsidiary folding, which has caused the formation of small synclinal areas plunging away from the central mass, there are several inferred faults. These, too, have caused topographic reentrants into the mountain.

The lower Paleozoic formations dip 5°-30°NW. and over large areas the Antietam sandstone probably forms the dip slope of the northern flank. Reading Banks is situated far down the slope of this north flank at an elevation of 600 feet, where the beds dip about 10°NW.

Ore Deposits

General Features

Manganese ore and manganiferous iron ore occur in three ways at the Reading Banks and in the reentrant near White Rocks, one mile farther southeast:

1. Solid mixed manganese-iron oxide ore with a slumped bedded character, containing thin interbeds of white and yellow clay, situated near and at the base of the Tomstown formation in contact with the Antietam sandstone.
2. Nodular cryptomelane and limonite in residual yellow clay slightly above the base of the formation.
3. Thin beds and stringers of cryptomelane and limonite in tan, yellow, and black clay, about 100 feet above the base of the formation.

The oxide ore follows the strike of the rocks and is persistently associated with the residual clay of the Tomstown formation.

In the Reading Banks pit the solid ore is visible at four places, all of them near the bottom of the pit (pl. 2, pocket). The best exposure is on the north face near the west end of the pit where the ore forms a face 35 feet high and bench at the top of it. The ore is interbedded with clay, and the entire face has a bedded character. The beds dip 6°-9°NW.

Above the face of the solid ore is a zone of about 15 feet of ore of type 3. Clay predominates, but thin beds of ore are all through it.

On the south side of the pit at its eastern end another face of solid ore is exposed. It stands 20 feet high and also makes a bench at the top. The overlying zone, 35 feet thick, is principally barren white clay.

North side	Feet	South side	Feet
Float	10	Float	20
Yellow clay and thin ore beds	15	White clay	25
Solid ore	35	Solid ore	20

[71] Foose, R. M., op. cit.

The trace of an old drift driven S.30°W. intersects solid ore at the bottom of the pit near the northeastern end. Solid ore is also exposed in the middle of the pit where trenching in 1940 penetrated it. A 20-foot shaft, sunk near the largest ore face, is in ore all of the way.

The solid ore, therefore, apparently floors the entire pit and is exposed at several places along the sides. The overlying wash ore is not as persistent. The grade of the solid ore is 5 to 8 percent of manganese.

Mineralogy

Ore minerals. The manganese and the iron minerals are all oxides. The manganese minerals include cryptomelane, psilomelane, manganite, pyrolusite, and wad.

The chief mineral is cryptomelane (KR_8O_{16}(?), R = Mn^{IV} chiefly, also Mn^{II}, Zn,Co). In both the nodular form and the bedded form, it has the same physical properties. It is a dense, blue-black to steel-blue mineral having a hardness of 6.5, a sub-metallic luster, a black streak with a brown tinge, and a specific gravity of from 4.29 to 4.43.[72]

Chemical tests showed a significant percentage of K_2O and a dearth of BaO. X-ray powder patterns are identical with those of cryptomelane from other localities.

Optical examination, microchemical and etching tests on polished sections of the ores proved unsatisfactory for identification. The mineral could be classified as psilomelane or cryptomelane on the basis of these tests.

The cryptomelane occurs in the following ways:

1. Replacement mineral (chief type).
   a. Irregular massive replacement of clay, and of Antietam sandstone.
   b. Tabular replacement of thin-bedded clay.
   c. Replacement veins and veinlets in brecciated limonite, and rarely in clay.
   d. Nodular and botryoidal replacement in clay.
2. Impregnation or matrix mineral. Small amount of cryptomelane fills brecciated limonite and Antietam sandstone (pl. 10).
3. Precipitation mineral in cavities. Stalactitic forms occasionally developed, accompanying limonite.

The most common exposed occurrence of cryptomelane is as a bedded replacement associated with limonite (B.S.-1b and pl. 11, A). The grade of this ore, because of its intimate association with limonite, is less than 10 percent of manganese.

Occurrence as small veins and veinlets is also common. Small veins cut across older limonite and sometimes fill reopened limonite veins (pl. 13, B). This type is frequently associated with the bedded type.

True psilomelane (Ba $R_8O_{19}.2H_2O$(?), R = Mn^{IV} chiefly, also Mn^{II}, Co), has tentatively been identified from the Reading Banks pit. Part of the bedded ore, having the same physical properties as

[72] Gravity by Jolly balance; bedded ore, 4.29; nodular ore, 4.43.

cryptomelane, except that it is blacker and has a specific gravity of 4.52, shows a strong positive test for barium, indicating a high BaO content, and a negative test for potassium. The identification was not checked by X-ray determination, but the data are considered to be sufficiently diagnostic. The mineral forms a thin bed, separated by only 3 inches of clay from a bed of cryptomelane from which it cannot be distinguished megascopically. Similar closely associated occurrences of the two minerals have been reported.[73] In view of the difficulty of distinguishing between these two minerals, more of the true psilomelane may be present than is supposed.

Manganite ($Mn_2O_3.H_2O$) occurs in the ore at Reading Banks as small veinlets, not more than one-eighth inch thick, which cut across limonite (pls. 17, A and 18, A). The central part of one of the manganite veins studied under the microscope is composed of hundreds of prismatic crystals too small to determine their optical orientation. Manganite was not identified megascopically, but its optical properties are diagnostic. It is strongly anisotropic; the polarization colors are white, light grey, violet, brown, and dark grey. The streak is deep brown. Etch tests confirm the identification (B.S.-9a).

Since manganite is frequently a hypogene mineral, it is possible that the presence of cross-cutting manganite veinlets indicates late hypogene activity.

Pyrolusite (MnO_2) and wad, the soft, black aggregation of manganese oxides, occur as alteration minerals, associated in very small amounts with cryptomelane. Pyrolusite has also formed by the alteration of manganite, retaining the prismatic form of the manganite, in one of the small veinlets. Wad is superficial. It occurs most abundantly in the black clay associated with the wash ore above the more solid ore at Reading Banks.

Iron oxide occurs in three different generations and is of three distinct physical types.

1. Early, rust-colored, amorphous iron oxide (pls 11, A and 13, A).
2. Later dark brown and black amorphous iron oxide which usually replaces most of the first type (pls. 11, A, 13, A, and 15, A).
3. Late, crystalline, golden-colored goethite which selectively replaces colloform bands of iron or manganese oxide. This type is rare. (B.S.-2 and B.S.-9). It was not recognized megascopically.

The main mass of ore at the Reading Banks pit is manganiferous iron ore. In the vicinity of White Rocks, however, the manganese oxide and the iron oxide occur in separate nodules. The iron oxide nodules are composed of dark brown, amorphous limonite like that of type 2.

Gangue minerals. The chief gangue mineral at Reading Banks is quartz. It is clear and sub-angular, averages .02 mm. in diameter, and locally comprises as much as 10 percent of the ore mass.

Accessory gangue minerals include zircon and tourmaline. Masses of clay and of brecciated Antietam sandstone comprise a large portion of the gangue locally. These usually can be easily removed by crushing and washing.

[73] Fleischer, M., Washington, D. C., personal communication, March 26, 1942.

Structures and textures. Colloform texture is dominant in most of the nodular ore and in some of the bedded ore (pls. 16 and 19, A). Associated with this texture are typical reniform and botryoidal structures (pl. 12, A). The colloform texture is indicative of rhythmic growth. The nature of the individual bands changes because of the changing character of the solutions that deposited the mineral matter. The changes, however, are small for the most part and can be recognized only by slightly changing reflectivity or color of the bands in polished section. The environment influences the nature of the texture. In most cases, fragmentary unreplaced minerals, like quartz and limonite, are large enough that the mineral-bearing solutions "flowed around" them during deposition, causing a deflection of the colloform banding (fig. 21, A). Wherever the quartz and limonite average less than .02 mm. in diameter, they have been moved by the solutions and oriented parallel to the colloform banding (fig. 21, B).

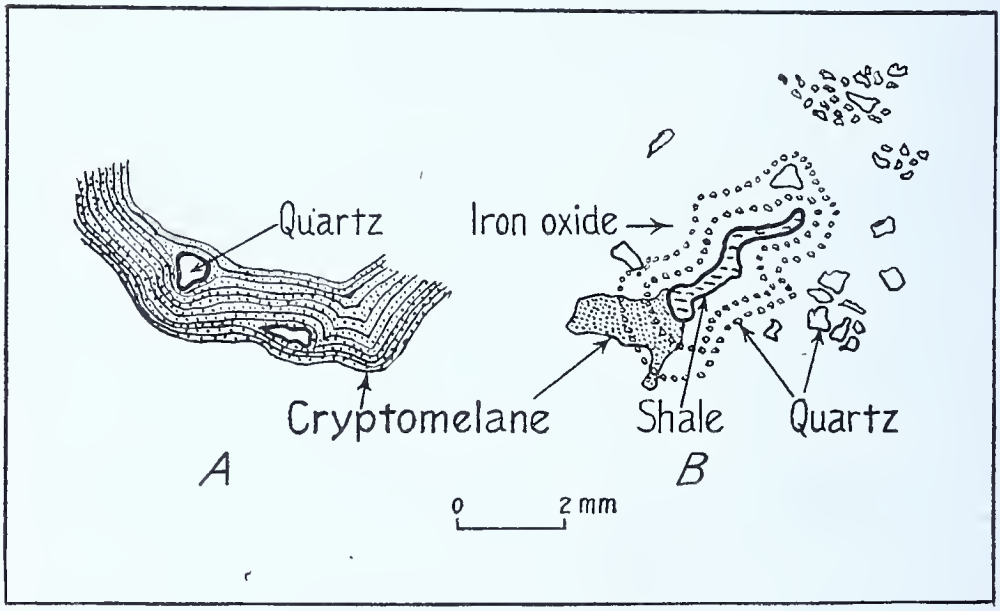


Figure 21. Colloform banding:

A. Showing orientation of banding around earlier minerals.

B. Showing aligned orientation of earlier minerals by the banding.

Stalactitic forms are common in some parts of the iron oxide ore. There is a definite sequence of growth (pl. 14):

1. When the stalactites are incipient and small, averaging 1 mm. in diameter and less, they are concentrically banded with hollow spaces, or spaces filled with clay, between each band except for thin connecting "supports" from one band to another.
2. As the stalactites increase in size to a diameter of 2 and 3 mm., the separated bands begin to coalesce.
3. When the stalactites are 3 to 5 mm. in diameter, the coalescence is complete and no trace of the former structure remains.

4. Other small stalactites begin forming in intervening spaces between two larger coalescing stalactites. Radial cracks commonly develop in the larger structures.

These stalactitic structures developed by concentric colloform growth. Radial fracturing seems to indicate further that the solutions were gel-like in nature, and shrinkage during solidification was responsible for the fracturing. The suggestion of differential shrinkage of the gel-like mass is indicated also by small displacements along some of the radial cracks.

Though colloform texture is ubiquitous, not all of the ore is so banded. Most of the ore has a nondescript texture as the result of unreplaced quartz grains in the ore mass.

Paragenesis. The sequence of events at Reading Banks is confused in some of its details. but the general outline is simple (pls. 11-19):

1. Replacement of yellow, arenaceous, Tomstown clay and part of the Antietam sandstone by first generation rust-colored limonite.
2. Fracturing and brecciation of the iron oxide ore mass, probably due to slumping of clay.
3. Replacement of the brecciated mass by second generation black and dark brown limonite.
4. Replacement by veinlets and larger masses of cryptomelane.
5. Replacement by veinlets of manganite.
6. Replacement of cryptomelane and manganite by crystalline goethite.
7. Alteration of manganite to pyrolusite and of cryptomelane to pyrolusite and wad.

Stages 3, 4, and 5 are so nearly contemporaneous that sequence 3 and 4 may be reversed and sequence 4 and 5 may be reversed, but stage 5 is definitely later than 3. Where the second generation dark limonite occurs as an irregular replacing mass, it is earlier than cryptomelane. Where it is later than cryptomelane, it occurs as veins. The latter form is the less common.

The manganite and cryptomelane seem to be practically contemporaneous, yet cryptomelane is clearly of supergene origin and there is a possibility that the manganite is of hypogene origin.

The goethite is uncommon and occurs as a selective replacement of colloform bands in cryptomelane and manganite, and also as tiny lens-like patches in a mass of cryptomelane (fig. 22, A and B). Evidently, it represents a small amount of iron oxide carried in solutions nearly saturated with manganese oxides; it is altogether possible that the limited amount of iron oxide represents the solution of part of the first or second generation limonite. In most cases the goethite clearly formed from the manganese oxide solutions after most of the manganese oxide was precipitated.

The formation of pyrolusite and wad are the result of alteration processes. Pyrolusite occurs as needle-like prismatic crystals. pseudomorphous after manganite,[74] and as amorphous material.

[74] Thiel, G. A., The manganese minerals: Econ. Geol., vol. 19, p. 126, 1924.

Chemical Composition of the Ore

The accompanying table of 7 analyses indicates the general chemical nature of the ore from Reading Banks and the vicinity of White Rocks. Samples marked "lump" are selected; those marked "R.R. car" represent run-of-mine ore with a very rough handpicking.

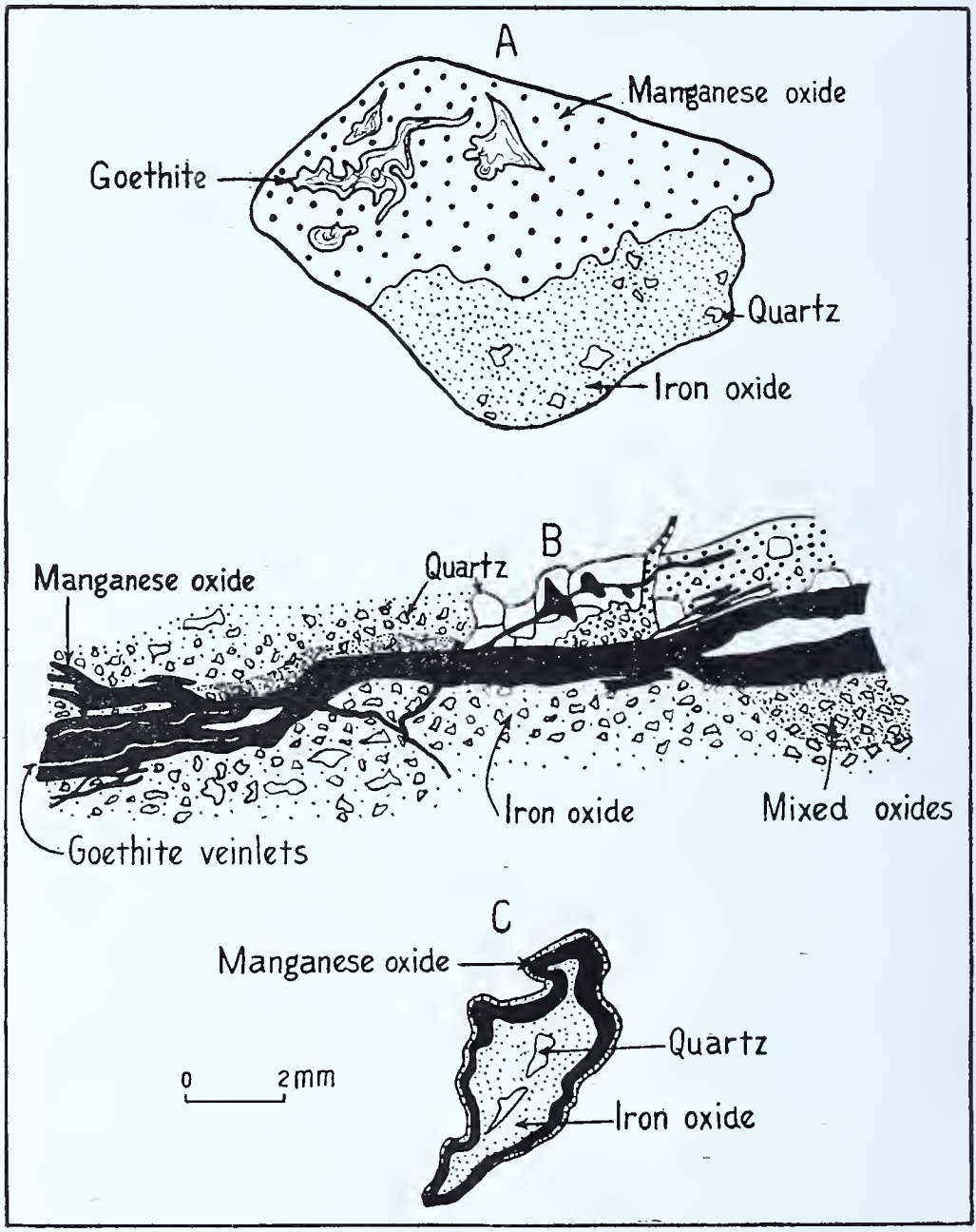


Figure 22:

A. Replacement of manganese oxide by goethite.
B. Brecciated siliceous iron oxide replaced by veins of manganese oxide and goethite.
C. Alternate banding of iron and manganese oxide, a result of rhythmic deposition.

Table 9. Analyses of Ore from Reading Banks and White Rocks

Character of sample	Mn	Fe	SiO_2	P	Analyst
lump	46.36	11.11	—	0.42	E. J. Lavino Co.
"	47.31	9.21	1.28	0.26	" " " "
"	1.49	48.25	—	0.95	" " " "
R. R. car	13.69	33.19	—	—	Alan Wood Steel Co.
" " "	9.33	40.39	—	—	" " " "
" " "	6.68	41.25	—	—	" " " "
lump (White Rocks nodule)	41.80	19.60	6.67	0.63	Pittsburgh Testing Laboratory

The manganese content of the Reading Banks ore averages less than 10 percent. The iron content ranges from 30 to 50 percent. The phosphorus content is very high and would present serious metallurgical difficulties which could possibly, however, be overcome. The percent of silica is not objectionable.

Relation of the Ore to the Clay

With exception of a small amount in the Antietam sandstone, the ore is all associated with clay residually weathered from the Tomstown dolomite. Most of the ore in the clay is of replacement origin.

The clay is heterogeneous, but certain general features prevail. Its color is predominantly tan, buff, and yellow; some is white and, where it is impregnated with soft, black manganese oxide, it is black. The thickness of the clay is variable. At Reading Banks more than 100 feet of the basal Tomstown formation is clay; part of it is now replaced by ore. The clay is arenaceous; clear, unstrained, subangular quartz grains, averaging .02 mm. in diameter, unaltered from the semi-clastic basal beds of the formation, comprise 10 to 20 percent of the unreplaced clay. The remainder is composed chiefly of kaolinitic matter. Very small amounts of primary sericite locally remain. Replacement by manganese and iron oxide is limited mainly to the kaolinitic matter; the quartz is sometimes partly, and rarely completely replaced.

The volume of the clay is obviously smaller than the corresponding volume of dolomite from which it weathered. The amount of shrinkage is not known because of lack of exposures of the original formation in the area. Shrinkage of the clay mass occurred partly subsequent to ore deposition because the crudely bedded ore is slumped and broken along with intercalated beds of clay. Likewise, stalactitic forms of the oxides, which must have formed in cavities, are broken and surrounded by clay with slumped and deformed laminae. The stalactitic forms are found where the clay is thickest.

Genesis

The exact source of manganese and iron is not known. Since the ore is supergene, it is somewhere in the sedimentary series starting with the Tomstown formation and including the overlying beds. Logically, it is limited to the Tomstown and the immediately over-

lying Cambro-Ordovician limestones and does not include the beds of late Ordovician age and those above it. Logically, too, the main source is most likely in a clastic series of beds which would contain mineral impurities rather than in relatively pure, chemically precipitated limestones. Therefore, the semi-clastic beds of the Tomstown formation which form a transitional sequence from the clastic Antietam sandstone below to the nearly pure, thick limestones above, are the most probable source.

The manganese was carried downward as a minor constituent of predominantly iron-bearing waters in a soluble form, probably the carbonate or bicarbonate. These solutions penetrated the clay and dispersed in all directions, controlled chiefly by laminae and cracks in the clay and, ultimately, by the very resistant, less pervious medium of the underlying Antietam sandstone. Dispersion of the solutions in the clay and ponding at the base of the clay overlying the sandstone was accompanied by replacement of the host clay by the oxides of both iron and manganese.

The nature of the solutions can only be inferred from the texture of the ore and the physical conditions under which it accumulated. Colloform texture, which is prominently developed in much of the ore, is indicative of a colloidal solution, or at least a gel-like stage through which the solutions passed. This condition implies a moderately warm temperature of the solutions. Downward moving and, or, laterally circulating waters may be warm at depth of 500 feet. This depth is probably the maximum average depth at which the ore accumulated, because it bears a direct relation to the overlying erosion surface and the limit of circulation of ground water. The ore at Reading Banks occurs approximately at the level of the old Tertiary erosion surface, 550 to 600 feet above sea level. Manganese evidently was concentrated through the erosion of the overlying sedimentary rocks during a long period of time and concentrated at the base of the zone of weathering of this old erosion surface, aided by favorable structural and stratigraphic conditions. The most common form of manganese oxide is cryptomelane in which the manganese is tetravalent and divalent (Mn^{IV} and Mn^{II}), and thus indicative of neutral or slightly acid conditions. Based on textural and physical conditions, therefore, the ore solutions were probably moderately warm, relatively shallow, slightly acid ground waters.

The chemical character of the solutions changed during the time of ore accumulation. At the beginning they were mainly iron-bearing; later they were manganese- and iron-bearing. Between the two stages there was a definite time break. The alternate deposition of iron and manganese oxides and the resultant confused age relations between the two during the second latest stage of ore deposition is attributed to locally different chemical composition of the solutions and to constantly changing composition due to the removal of one element from solution by deposition and the relative concentration of the other.

Mining and Milling

When the Reading Banks pit was operated in 1940, stripping methods were used. A steam shovel and, later on, a drag line moved the clay and ore. Trucks carried the material to dumps and stock

pile. At the stock pile, one mile west of the pit, on the southeastern edge of Boiling Springs, the ore was crushed and screened to 3-inch size, using a Blake jaw crusher. Crude hand picking of the large ore chunks eliminated some of the iron oxide.

Economics

Size of the ore body. The ore body at Reading Banks is, of course, not limited to solid ore. Practically speaking, it is all of the clay at the base of the Tomstown formation which includes enough ore to be profitably mined. At the Reading Banks pit the amount of ore removed is about 700,000 tons. The volume ratio of ore to clay which has been moved is about 2½ parts of clay to 1 part of ore. On the basis of exposures of the ore and the limited exploration work conducted at Reading Banks during 1940 and 1943, it is estimated that at least 150,000 tons of manganiferous iron ore is within easy access from the old workings.

Grade of the ore and recommendations. It was pointed out in discussing the chemical composition of the ore that the phosphorus content is very high and would probably cause metallurgical difficulties. The low percent of manganese and the high percent of phosphorus at Reading Banks is unfavorable. However, modern blast furnace practice can handle ores with fairly high phosphorus content. Therefore, prospecting by drill holes down the dip, north of the pit, to determine the character and extent of ore at depth would be warranted, especially if there were real need for domestic manganese ores.

DESCRIPTION OF LOCALITIES

BEDFORD COUNTY

Sherman Valley Area (1)*

The Sherman Valley area is discussed under the heading of Commercial Possibilities.

Robinsonville-McKees Gaps (2)

The Catskill red shale and sandstone is stained with black manganese oxide along the joint and bedding planes at many places in the vicinity of Robinsonville and McKees Gap (Clearville sheet). Small pieces of "psilomelane type" minerals, some of them partly altered to pyrolusite, were found on the western flank of Rays Hill near the Gap. Stevenson reported pyrolusite "of excellent quality" associated with "brown hematite" on the west side of Rays Hill.[75] The ore is probably eroded from the Pocono which is locally ore-bearing throughout Bedford County.

There are not enough of the manganese minerals to have any commercial importance.

BERKS COUNTY

There are no important occurrences of manganese minerals in Berks County. Oxide was observed in the Triassic sandstone east of Birdsboro (2) near the Schuylkill River. Small, earthy masses of wad are scattered on the surface over several small areas. There is no obvious source of the oxide.

Manganese oxide, mainly wad, has been reported from a place half a mile south of Reading along the Morgantown road (1), on the old Nathan Althouse farm along Maiden Creek (3), and near the village of Lyons (4).[76] These three localities are underlain by the Beekmantown or Tomstown limestones, and the oxide is probably weathered from isolated patches in those formations that are known to bear manganese and iron oxides at many places. A thin deposit of wad at least 20 feet square was discovered near Manatawny (5) associated with a hematite ore body in the Tomstown limestone on the property of the Manatawny Bessemer Ore Company. Genth reports pyrolusite from the county.[77]

Miller [78] lists analyses made by A. S. McCreath from five magnetite mines in Berks County, all of which contain minor amounts of manganese. The old Clymer mine, about one mile southeast of Pricetown, produced ore which locally carried 7.5 percent of manganese. Other localities which produced iron ore containing one and two percent of manganese were the Talley mine, Oley Township, and the Guiterman mine on the Gehman tract (6), Seisholtzville. With the exception of the Clymer mine, the percent of manganese is too small to be significant.

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[75] Stevenson, J. J., The geology of Bedford and Fulton counties: Penna. 2d Geol. Survey, vol. T2, pp. 211, 316, 1882.

[76] D'Invilliers, E. V., Geology of Berks County: Penna. 2d Geol. Survey, D 3, pp. 218, 399, 400, 402, 1882.

[77] Genth, F. A., Mineralogy of Pennsylvania: Pa. 2d. Geol. Survey, B, p. 45, 1875.

[78] Miller B. L., Manganese occurrences in eastern Pennsylvania: Penna. Geol. Survey, Bull. 47, p. 9, 1922.

* Number in parentheses indicates location on Figure 6.

Mammillary psilomelane occurs in arkosic Triassic sandstone about three-quarters of a mile west of Joanna Station in southern Berks County (7). The psilomelane nodules have replaced the sandstone and commonly enclose quartz grains and pebbles. The occurrence was prospected by test pits about 1915; it has no commercial importance.

BRADFORD COUNTY

Barclay Coal Basin Area (1)

Nodular pyrolusite has been reported to occur along the slopes of Rollison Run and Big Schroeder Run in the Barclay Coal Basin Area of southwestern Bradford County.[79] The nodules are described as 6 to 8 inches in diameter and occurring at an elevation of 80 feet above Schroeder Run at the mouth of Rollison Run. They apparently weathered from the basal beds of the Mauch Chunk shale.

BUCKS COUNTY

Genth mentions in his Mineralogy of Pennsylvania the occurrence of psilomelane in gneiss at Pennypack Creek, three miles from Bustleton, Bucks County. The occurrence is actually in Philadelphia County about one-eighth of a mile south of the county line. A few small nodular pieces are scattered on the surface as erosion remnants of small oxide pockets. Source of the manganese is chiefly the mineral spessartite, common to the Piedmont gneiss rocks.

CAMBRIA COUNTY

The presence of manganese in many of the analyses of clay from Cambria County is noteworthy because of its absence from Clearfield County clays.

CENTRE COUNTY

Wyre Bank (1)

The old Wyre iron ore bank, worked between 1852 and 1857, is located four miles northeast of Warriorsmark (Tyrone sheet). The open cut is slumped and the ore concealed. Lesley reported "good open ore, bluish, and heavily charged with manganese". This ore occurred at the west end of the open cut.

The description of the ore fits in a general way the mineral cryptomelane or psilomelane. Apparently it was crudely bedded and broken and slumped in the tan and white sandy clays residual from the basal Gatesburg formation.

During late 1943, three churn drill holes were drilled by the U. S. Bureau of Mines within 500 feet of the old workings. These holes were drilled in connection with a project of exploration for iron ores in the central part of Pennsylvania. A moderate amount of ore was indicated by these three holes and by several others at a greater distance from the old workings, but the amount of manganese ore was not indicated. In any case, these few holes did not indicate the general area to be favorable.

Because the holes were widespread and did not give much information right around the workings, it would be worthwhile to investigate

[79] Platt, F., Report of progress in Bradford and Tioga Counties: Penna. 2d Geol. Survey, vol. G, pp. 124, 125, 1878.

this occurrence further by several methods of exploration. Hand auger holes in the bottom of the old workings would be inexpensive and afford the means of determining the possible downward extent of the ore minerals, at least to depths of 25 feet. The holes should be spaced on a regular pattern. These could be augmented by well placed test pits that would afford larger samples and serve as a correlation between the auger holes. Exploration should also include the area immediately adjacent to the old workings to indicate possible lateral extent of the ore.

CHESTER COUNTY

Sharpless Farm (1)

The Isaac Sharpless birthplace and farm is on the east side of the Birmingham road, three miles south of West Chester and one mile south of Strodes Mill. It is reported that manganese ore was removed from an old opening made before 1900[80] in the face of a hill 1350 feet northeast from the old home along Radley Run, which flows through the meadow. The old drift has long since caved and there is only a shallow swampy area roughly 12 by 14 feet to mark its position. There is no evidence of a dump, and no record of actual ore production. The opening must have been a very small prospect.

Careful examination of the swampy area and the entire hill revealed very little evidence of manganese minerals. A black film of wad covers some of the gravel and small pieces of hornblende gabbro which lie in the swampy area. It is known that spessartite, a manganese-bearing garnet, is associated with the Baltimore gneiss and the intrusive gabbro rock which underlie this region. The contact of the gabbro and gneiss is half a mile north of the farm. Surface waters have doubtless taken some of the manganese into solution, from which it has been precipitated as films of manganese oxide.

French Creek Falls (2)

Small quantities of pyrolusite and wad have been found near the magnetite mines along French Creek in northern Chester County. One shaft went through a small concentration of wad at the base of 40 feet of residual clay.[81] The presence of manganese is noted in six analyses of the French Creek magnetite ores,[82] ranging from .10 to .16 percent. This is one of the few places in Pennsylvania that manganese is of definite hypogene genesis, having its ultimate source in the parent magma of the Triassic diabase that intrudes pre-Cambrian (?) limestone and Triassic sandstone and shale at this place.

CUMBERLAND COUNTY

Reading Banks and White Rocks (1)

The occurrence of manganese minerals at Reading Banks is discussed under the heading of Commercial Possibilities. Bulletin M-26, titled "The Iron-Manganese Ore Deposit at White Rocks, Cumberland County, Pennsylvania", describes the ore deposit in considerable detail.

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[80] Sharpless, F. P., Lancaster, Pennsylvania, Personal communication, July, 1941.
[81] Miller, B. L., Manganese occurrences in eastern Pennsylvania: Penna. Topog. & Geol. Survey, Bull. 47, p. 10, 1922.
[82] Smith, L. L., Magnetite deposits of French Creek, Pennsylvania: Penna. Topog. & Geol. Survey Bull. M 14, p. 43, 1931.

McCarrick Prospect (2)

Manganese ore has been mined on a property, now owned by the brothers McCarrick, one mile southwest of Mount Holly Springs (Carlisle sheet) along the north flank of South Mountain at an elevation of about 700 feet. The property is underlain by the Antietam sandstone near its contact with the Tomstown formation. The formations dip gently northwest off the flank of the mountain. An old shaft, driven about 1880, reported to be 60 feet deep, penetrated ore at several horizons. The ore was removed and shipped to a nearby furnace for smelting. In 1940, the McCarricks excavated two pits (50 by 30 by 30 feet and 40 by 20 by 20 feet) in the soft, weathered mantle and tan arenaceous clay, residual from sericitic horizons in the top of the Antietam sandstone. These pits revealed a small quantity of lump manganese and iron ore, some nodular and reniform, others of irregular and crudely banded form.

Pyrolusite and cryptomelane are the two manganese minerals, occurring in nearly equal abundance.

Pyrolusite occurs as nodules with irregular concentric banding and rough bulbous surfaces. Pieces of unreplaced white and yellow Antietam sandstone, ranging from small specks to one inch in length, stand out in relief on many of the nodules. Some of the larger pieces of sandstone still retain bedding (fig. 4). The nodular surfaces are weathered to a soft, dark brown hydrous oxidation product, probably wad. The pyrolusite is black, with scintillating points of minute unreplaced quartz, has a dull earthy luster, a hardness of 3, a deep black streak, and a specific gravity of 5.1.[83] The identification was checked by an X-ray powder photograph. It is a replacement mineral

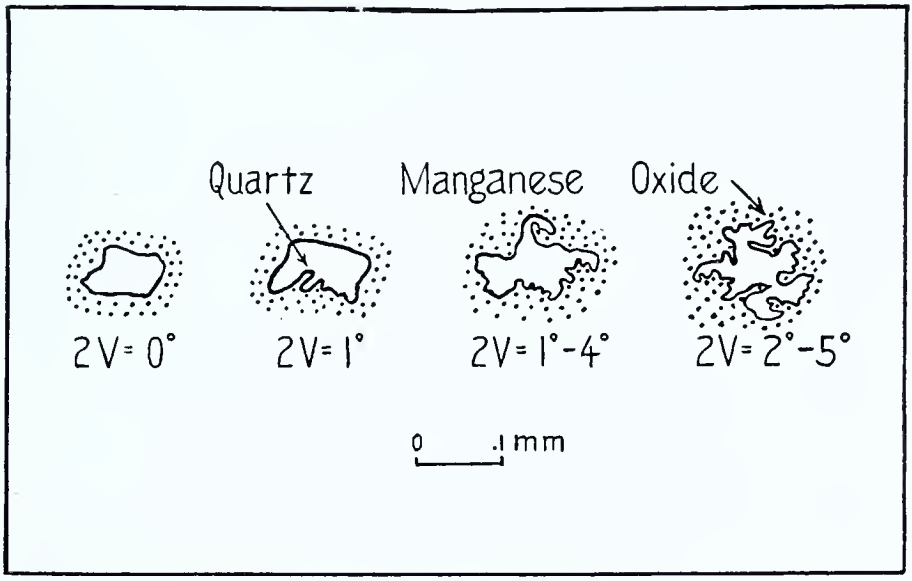

Figure 23. Relation of strained quartz to amount of replacement by manganese oxide

and deeply embays quartz grains (fig. 23) and large quartzite fragments of the Antietam sandstone (Mc-1). Rarely is the replacement

[83] Determination by Jolly balance.

complete. The pyrolusite retains the granular appearance of the original sandstone.

Hard lumpy cryptomelane occurs mixed with the pyrolusite. It is blue-black, dense, has a brownish-black streak, and a hardness of 6. The ore shows a crude zonal arrangement in some lumps due to the alteration of some layers of cryptomelane with pyrolusite. Excellent colloform texture characterizes the cryptomelane. Quartz and sandstone fragments in the ore indicate cryptomelane is also a replacement in the Antietam sandstone.

Wad occurs as an alteration product of both cryptomelane and pyrolusite.

A few isolated patches of limonite replace pyrolusite (Mc-1).

The paragenesis of the minerals from older to younger is:

1—Pyrolusite and cryptomelane contemporaneously.

2—Limonite.

3—Pyrolusite and wad as alteration products.

There is not sufficient concentration of the oxide minerals to make a commercial deposit. The grade of some of the ore is good, however. One analysis shows 47.24 percent of manganese, 1.20 percent of iron, and 1.80 percent of silica.[84] Both of the pits are in pockets of residual clay but did not reach the bottom. Possibly there is concentration of the oxides at greater depths.

Wharton Mine (3)

Cryptomelane and pyrolusite occur at the Wharton mine three miles southwest of Mounty Holly Springs at an elevation of 1,000 feet on the north flank of South Mountain (Carlisle sheet). Manganese ore was mined, washed, and shipped from this locality about 1880. The old pit, 125 by 125 by 30 feet, and the site of the log washer remain, and fine washed manganese ore of high grade covers much of the ground near the site of the old washer. During 1940, Mr. Jack McCarrick, of Mount Holly Springs, drilled 25 hand-auger holes 20 feet deep across the bottom of the old pit. Only a few feet of black clay was encountered in several of the holes.

The ore occurs in a weathered part of the Antietam sandstone, and high enough on the mountain so that the horizon may be toward the middle of the Antietam. There are no outcrops in the immediate vicinity, so the structure cannot be accurately interpreted; the location is on the western side of a topographic reentrant, or valley, which heads south into South Mountain, and this may also be a structural reentrant caused by a synclinal roll in the beds which dip toward the northwest and/or normal faulting. In any case, structural control has probably influenced the location of the ore.

Pyrolusite is the chief mineral. It is soft, black and porous, with a dull earthy luster. It was identified by X-ray powder photographs. It occurs mainly as an alteration of cryptomelane.

Cryptomelane may have been present in greater abundance when the ore was mined; only a few pieces were found in July and November 1941. Microscopic examination shows that massive, colloform-

[84] Analyst, Pittsburgh Testing Laboratory, November 1941.

textured cryptomelane was cut by later veins of the same mineral. Pyrolusite developed along the colloform bands and eventually replaced the entire mass with the exception of some second generation cryptomelane veins.

The dominant texture is porous and granular. The almost complete alteration (pl. 24, B) and its ragged, porous nature seems to indicate the change took place by normal weathering processes during which there was a change from alkaline to acid conditions of the surficial waters.

Nodular ore from the Wharton mine contains 39.34 percent of manganese, 9.00 percent of iron, and 9.62 percent of silicia.[85] This is good manganese ore. The exploration work during 1940 suggests the ore deposit was a small one and has been exhausted. However, hand auger holes, and possibly several test pits, would be merited around the periphery of the old workings to determine possible lateral extent.

Clever Mammoth Banks (4)

More than five percent of manganese was reported in several analyses of ore from the two Clever ore banks, three miles southeast of Shippensburg (Newville sheet).[86] No manganese minerals were found when they were examined in July 1941. These banks, like most of the mountain ores along the flank of South Mountain, are in the basal ore-bearing beds of the Tomstown formation.

Laurel Banks (5)

Manganese oxide occurs in the form of replacement veins and masses in the iron oxide ore at Laurel Banks, near Pine Grove Furnace (Newville sheet). The Laurel Banks produced iron ore for many years prior to 1900 from the tan residual clay of the basal Tomstown formation. Locally manganese oxide occurs in large quantities and is of good grade. The average, however, is less than five percent of manganese.

The sequence of events during formation of the Laurel Banks ore was (L.B.-1):

1. Arenaceous clay, containing fragments of quartzite and vein quartz, was replaced by rust-colored iron oxide.
2. Replacement of the mass by dark brown and black iron oxide.
3. Shattering, causing fine cracks through the quartz grains and the ore.
4. Infiltration of manganese oxide which irregularly replaced the black iron oxide, isolating irregular fragments of the iron oxide, .05 mm. in diameter, in the manganese oxide. Tiny veinlets, less than .1 mm. wide, penetrate the ore. The manganese oxide is mainly associated with the black iron oxide and is most abundant where there are unreplaced quartz grains, especially near the larger grains. Apparently these places afforded easier migration for the manganese-bearing solutions.

[85] Analyst, Pittsburgh Testing Laboratory, Nov. 1941.
[86] McCreath, A. S., Report of Progress: Penna. 2d Geol. Survey, vol. M 3, pp. 15, 16, 1881.

An analysis of some of the Laurel Banks ore showed 25.34 percent of manganese, 30.10 percent of silica, and a low phosphorus content of only 0.056 percent.[87] This is not representative of the average ore mined or what may remain. In view of the fact that the ore pits are flooded and that the average manganese content is not very great, these banks are not considered to be a potential commercial source of manganiferous iron ore. If manganiferous iron ore of 5 percent (Mn) grade should assume importance, this area should be prospected.

DELAWARE COUNTY

Several specimens of wad have been collected from the Garnet Mines (1) in Bethel Township, one mile south of Chelsea (Chester sheet). The wad is associated with weathered gneissic rocks of the region. No pockets or bags of the material have been reported or observed.

Wad has also been reported to occur with limonite segregations in the decomposed hornblende gneiss in the borough of Darby (2).

These two occurrences resulted from the weathering of spessartite in the gneiss.

FRANKLIN COUNTY

Between Fayetteville and Mont Alto along the foot of the west slope of South Mountain are numerous old iron ore pits with residual clay pockets in the Tomstown dolomite (Chambersburg sheet). Almost all of them are reported to carry from one to five percent of manganese. A representative analysis of the ore from every bank is given by McCreath.[88] During this investigation manganese oxide minerals were found at two of the banks.

English Bank (1)

English Bank is located three miles north of Mont Alto at the south end of English Valley. It is a small pit, 60 feet in diameter and 45 feet deep with 5 feet of water in the bottom. Along the sides of the pit are pieces of nodular brown iron oxide ore half buried in the tan and yellow clay residual from the weathered Tomstown dolomite which overlies the Antietam sandstone and dips gently to the west.

There are two kinds of iron oxide: an early generation which is rust-colored, and a later generation which is dark brown and black and which has largely replaced the rust-colored type (E-1). Associated with the black iron oxide is a small amount of manganese oxide, also in two generations. The mineral is psilomelane or cryptomelane and it replaces some of the black oxide as veins one-sixteenth of an inch wide, and as irregular elongated masses up to half an inch long. The second generation manganese oxide may be simply a late precipitate from the iron-manganese solutions, for it occurs only in the middle of veins of the first generation manganese oxide and differs from it slightly, being "whiter", having higher reflectivity, and smoother texture. The rust-colored iron oxide is fairly siliceous, containing unreplaced sub-rounded quartz grains averaging .02 mm. in

[87] Analyst, Pittsburgh Testing Laboratory, Jan. 1942.
[88] McCreath, A. S., Report of progress: Penna. 2d. Geol. Survey, vol. M. 3, pp. 1-55, 1881.

diameter. Quartz content decreases in the black iron oxide and is absent from the manganese oxide.

The ore has formed by replacement of the residual clay by downward percolating iron- and manganese-rich solutions. Mineralization began with replacement by iron oxide alone and was continued by nearly contemporaneous deposition of iron and manganese oxides. The paragenesis of the minerals from oldest to youngest is:

1—Quartz—residual from clay and partly replaced.

2—Iron oxide, rust colored.

3—Iron oxide, dark brown and black, and early manganese oxide.

4—Manganese oxide, late.

An analysis of several pounds of ore showed 15.99 percent of manganese and 30.40 percent of iron.[89] The phosphorus content was reported as .849 percent by McCreath, which would make the ore nonsalable. Nevertheless, exploration by hand auger holes, trenches and pits in the vicinity is warranted, for analytical specifications on ores may well change. Also, improved metallurgical techniques may make it possible to use ores with higher phosphorus content.

Promise Bank (2)

The Promise Bank is located one-quarter mile east of English Bank, 10 yards to the south of the Mount Cydonia quarry road. Fragments of wash iron ore occur along the edge and on the inner flanks of the pit which is also in residual clay weathered from the Tomstown formation.

A few small specimens of manganese oxide ore were found. The manganese minerals are pyrolusite and psilomelane or cryptomelane. The pyrolusite occurs as a soft, black oxide which has locally completely replaced sandy iron oxide, preserving the granular texture. There is a thin peripheral deposit of cryptomelane in cavities and particles of cryptomelane, about one micron in size, are disseminated through the pyrolusite.

Manganiferous solutions apparently soaked through porous areas in the iron oxide ore and replaced it as pyrolusite. As a late precipitate, or perhaps as the result of later solutions, the disseminated cryptomelane occupied the tiny pore spaces and coated the periphery of cavities.

An analysis of some of the fragments showed 31.98 percent of manganese.[90] This represents selected ore and not an average of the main ore body, most of which has been removed. An analysis by McCreath showed less than one percent of manganese. Prospecting by a few pits within the old pit might be warranted.

Squire Stinger Bank (3)

Manganese oxide was reported from this old bank, but none was found when the locality was investigated in 1941.

[89] Analyst, Pittsburgh Testing Laboratory, January 1942.
[90] Analyst, Pittsburgh Testing Laboratory, January 1942.

Little Cove Area (4)

Soft, black, structureless manganese oxide occurs as an impregnation in the medium-grained, white Oriskany sandstone in Little Cove, five miles southwest of Mercersburg (Mercersburg sheet). Manganese-bearing waters percolated along joints and bedding planes in the sandstone, and filtered through it. Locally there is evidence of some replacement of quartz; for the most part, however, it is a spotty and unimportant impregnation.

FULTON COUNTY

Needmore Area (1)

Manganese oxide occurs as stains and thin coatings on the joint and bedding planes of the Catskill red beds and as occasional nodules and fragments of "psilomelane type" minerals and pyrolusite associated with limonite nodules on the east and west flanks of Sideling Hill near Whips Cove, four miles west of Needmore (Needmore sheet). The source of the manganese is probably the basal beds of the Pocono sandstone which locally carry nodular iron ores with a small manganese content. Stevenson reported the presence of scattered nodules of pyrolusite along the east side of Sideling Hill in Union, Bethel, Belfast, and Licking Creek Townships.[91]

Oregon Creek Area (2)

Nodular "psilomelane-type" minerals occur in patches along Oregon Creek and within Duvall Cove (Broad Top sheet). This area is discussed with the Sherman Valley area. (See plate 1.)

HUNTINGDON COUNTY

East Pennington Bank (1)

Manganese oxide, occurring both as nodular and bedded "psilomelane type" minerals, occurs at the old East Pennington iron ore bank about one mile west of Warriorsmark (Tyrone sheet). Like all the other old ore banks of this area, it is associated with the basal clays of the Gatesburg formation. The sides have slumped and the ore is obscured so the exact manner of its occurrence cannot be determined. Small specimens appear to be similar to the manganese oxide ore from the Huntingdon Furnace banks. The grade of the ore is good. Further investigation by several test pits and trenches seems warranted.

During the fall of 1943, the U. S. Bureau of Mines drilled several churn drill holes in the vicinity of both East and West Pennington Banks while conducting explorations for iron ores in the central part of the State. The indications of ore minerals in this area were very small. However, the north and east side of the old East Pennington Banks workings were not explored and it seems that several hand auger holes and test pits close to the limit of the old workings along these sides, may be merited.

[91] Stevenson, J. J., Geology of Bedford and Fulton Counties, Pennsylvania: Pa. 2d Geol. Survey, vol. T 2, p. 316, 1882.

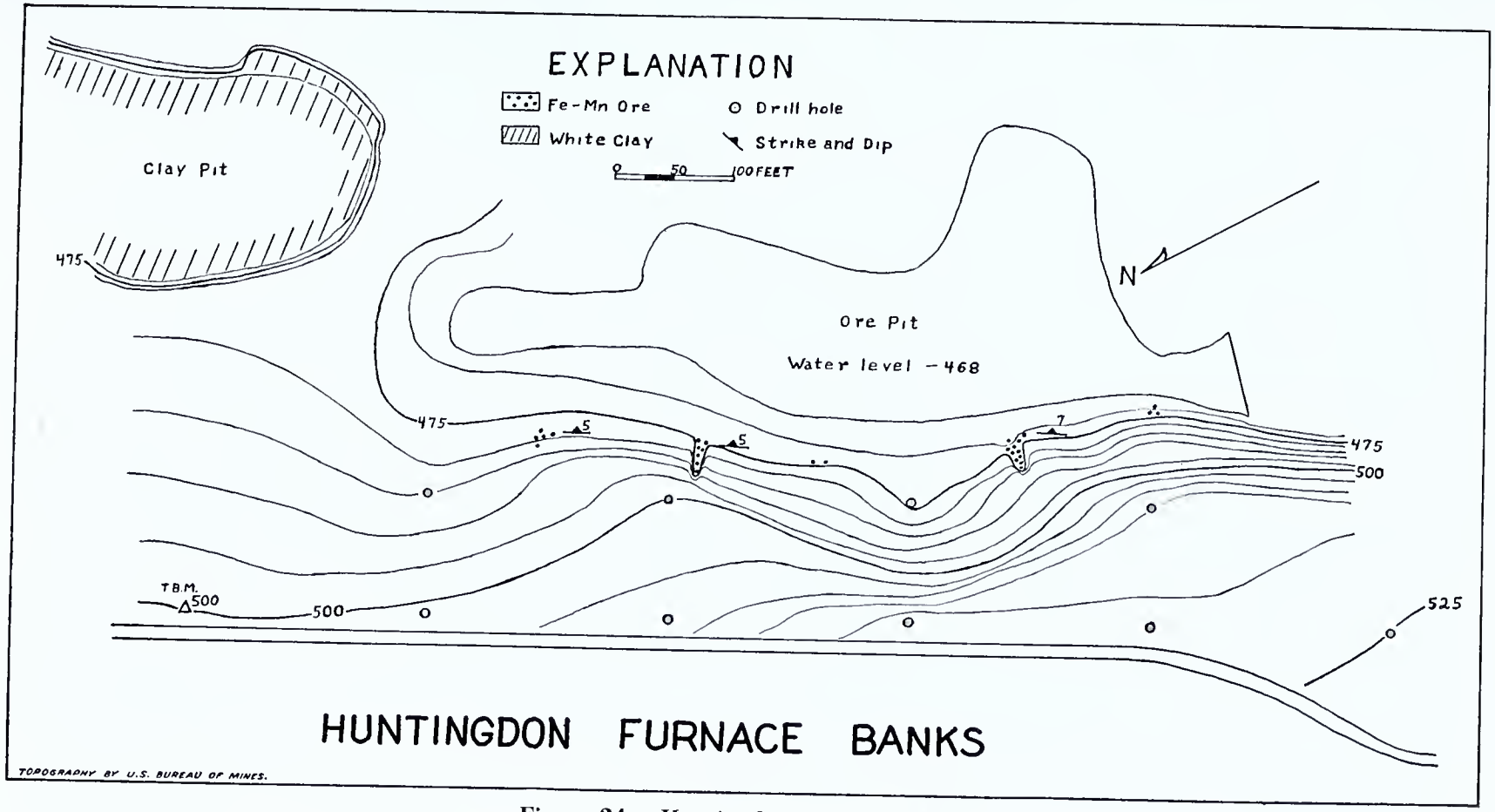

Figure 24. Huntingdon Furnace Banks.

Huntingdon Furnace Banks

The Huntingdon Furnace iron ore banks are along the southern slope of Dry Hollow Ridge, three miles south of Warriorsmark, in Huntingdon County. In the weathered clay horizon of the Cambrian lower Gatesburg formation, nodular and crudely bedded cryptomelane is associated with iron oxide (limonite). The banks are slumped and partly filled with water. Most of the property is owned by the Clinchfield Sand and Feldspar Company (Baltimore, Md.), which is now mining white clay. (See figure 24.)

The Gatesburg formation, composed of alternating sandy and dolomitic beds, has weathered to a residual sandy clay which carries the ore. There are no outcrops of the formation in the immediate vicinity, but the structure is revealed by the ore occurrence. Thin beds of iron and manganese oxide, replacements of original dolomitic beds, dip gently toward the southeast all along the northwest side of the pit. Besides the bedded ore, nodules of limonite and cryptomelane are locally abundant in the clay. The cryptomelane has a steel-blue color, semi-conchoidal fracture, a brownish-black streak and a hardness of 6 to 7.

Microscopic examination of the manganese oxide shows two generations of cryptomelane (figure 25). The earlier, which is probably

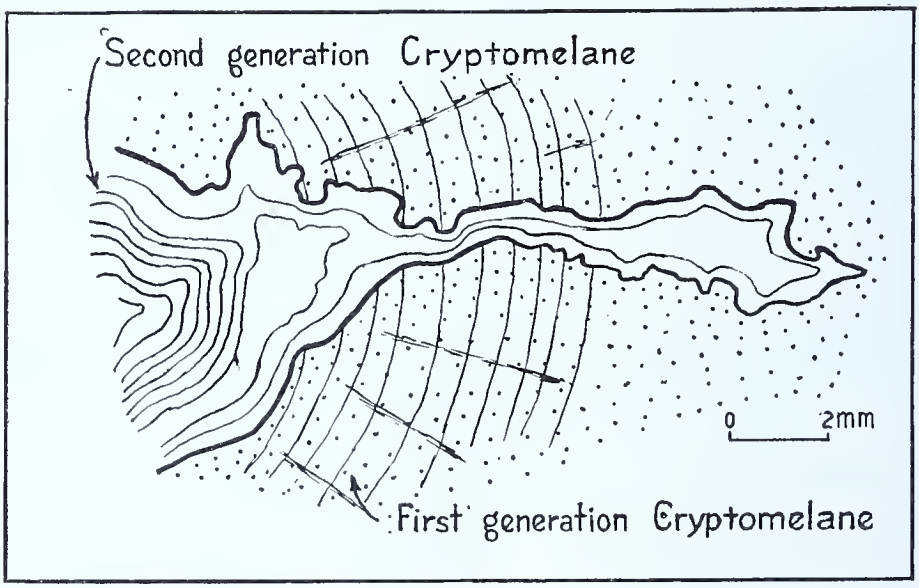

Figure 25. Relation of two generations of cryptomelane in Huntingdon Furnace ore.

later than the iron oxide that replaces the clay, forms the main ore. The second occurs in small colloform-banded veinlets along radial cracks across the concentric, banded structure of the first.

The manganese oxide is of good grade, containing more than 45 percent of manganese. The phosphorus content is not known. The surface occurrence of nodules would indicate an area more than 1,000 by 350 feet which may be ore-bearing. On the basis of these favorable indications, the State Geological Survey recommended drilling of the area.

During the early fall of 1942, the U. S. Bureau of Mines drilled five holes with a 16-inch diameter bucket drill to depths ranging from 20 to 65 feet and three hand auger holes 25 to 30 feet deep. All of these holes were drilled up the dip along the west side of the old water-filled workings at 200-foot intervals. With the exception of minor amounts of both manganese and iron ore near the surface (depth of 5 to 10 feet), there were no favorable indications of ore in the area of exploration. Further exploration by churn drilling in the general area east of the old workings was conducted during the fall of 1943 by the U. S. Bureau of Mines in connection with a program of exploration for iron ores in central Pennsylvania. Results of this drilling indicated no favorable concentrations of manganese ore.

On the basis of past exploration, the area might not be considered favorable. However, the good grade of the ore and the apparent quantity on the surface are sufficient reason for further exploring, by hand auger and test pit, the area immediately adjacent to and down the dip from the old workings on the east.

Orbisonia Area (3)

Manganese ore occurs at two horizons near Orbisonia. One is the medium-grained, white Oriskany sandstone and the other is a thin-bedded sandstone and fossiliferous chert of Helderberg age 80 to 100 feet below the Oriskany. The Helderberg horizon is exposed on the Frank White farm 2½ miles northwest of Orbisonia along Logan Run. Siliceous fragments and one or two homogeneous pieces of manganese oxide associated with ferruginous sandstone were found at an old slumped pit and on small dumps. There is nothing of value at this horizon.

Three hundred yards to the east, a small hill is capped by 20 feet of Oriskany sandstone, the lower part of which is impregnated with iron oxide along the bedding and the joints. A drift, now caved, once penetrated the hill along the strike of the rocks. The dump, located at the portal, contains large chunks of siliceous brown and black iron ore and smaller pieces of botryoidal cryptomelane or psilomelane, and wad. Ore was shipped at one time to Lavino in Pittsburgh and reported to average 33 percent of manganese. It is impossible to tell what the nature and grade of the ore may be. Specimens of siliceous manganese oxide were obtained from near the portal.

Black manganese oxide fills the space between sub-rounded quartz grains of the sandstone (O-1). Partial corrosion of the grain edges shows that the manganese-bearing solutions also attacked and partly replaced the quartz (pl. 25, A). A few small replacement stringers of manganese oxide cut strained quartz. Sixty percent of the quartz shows undulatory extinction and these grains are most fractured. Therefore, manganese oxide occurs to a large extent along fractures in strained quartz. Iron oxide, deposited prior to the manganese oxide, is replaced by the latter.

The body is apparently small and the grade not high enough to be a true manganese ore. Some prospecting to determine the physical character of the ore and its mode of occurrence would be warranted

only in case of serious need for manganese. Normally, prospecting would not be warranted.

Chester Furnace (4)

Rogers reported the presence of cellular brown iron ores carrying manganese near Chester Furnace.[92]

LANCASTER COUNTY

There are no important occurrences of manganese minerals in Lancaster County; oxide minerals have been found at several places.

A few small fragments of pyrolusite, associated with the Conococheague limestone, have been seen in East Cocalico Township (1).

Nodular manganese oxide occurs in very small amounts associated with the limonite at the old Chestnut Hill ore banks (Lake Grubb) near Silver Spring (4). It has also been seen at several places in the clay residually weathered from the Conestoga limestone in the vicinity of Beartown (2) and south of Quarryville (3). Beck[93] gives the analysis of "psilomelane" from Chestnut Hill: MnO_2 56.75, MnO 31.30, Fe_2O_3 6.44, Co(Cu.Ni) oxides 1.27, SiO_2 1.80.

LEBANON COUNTY

Small amounts of manganese minerals occur at Cornwall (1) associated with the magnetite ore body. Rhodochrosite, rhodonite, hausmannite, pyrolusite, wad, and cobaltiferous crednerite have all been found at the mines. None of them is common and most have not been observed in recent years.

LEHIGH COUNTY

Ironton Banks (1)

At Ironton, 6 miles northwest of Allentown in Lehigh County, there are 6 pits, now water-filled, from which limonite ore was produced for many years. The limonite occurs as geodic and shell-like ore mixed with yellow and white clays that represent the weathered residuum of the underlying Beekmantown limestone. Mixed with the limonite are variable amounts of manganese oxide, usually occurring as "psilomelane type" minerals.

It is impossible to examine the old workings. However, good descriptions of the workings and the nature of the ore exist.[94] The ore occurred in nearly horizontal, cavernous, bed-like masses. Some of these beds reached a thickness of 40 feet. Twice, according to Prime, local concentrations of psilomelane were encountered, the psilomelane ore making local beds in the limonite and in the clay. Prime interpreted the relatively lower position of one of the manganese beds with respect to an overlying bed of hematite as being due to the greater solubility of manganese than iron in natural solutions, and its subsequent deposition from those solutions at greater depth. This interpretation is probably correct, for similar relations between manganese and iron ores have been observed elsewhere in the State.

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[92] Rogers, H. D., Geology of Pennsylvania, p. 77, 1840.

[93] Beck, H. H., The minerals of Lancaster County: Linnaen Soc., 12 pp., 2nd ed., Lancaster, Pa., 1934.

[94] Prime, Jr., Frederick, Lehigh iron ore district: Penna. 2d Geol. Survey, vol. D D, pp. 27-29, 1878.

About 1910 the mines were operated by a Dr. Hartzell and it is reported[95] that he encountered a number of small psilomelane bands in the limonite, one of them being a fair-sized lens that attained a 4-foot thickness, but which soon ended in the limonite.

A careful examination of the dumps at the Ironton pits revealed very little evidence of the occurrence of manganese minerals. The ore mineral is of "psilomelane type" and it occurs intimately mixed as small veinlets in the limonite ore and as separate bands and lenses in the limonite mass. Several small, isolated nodules of the mineral were seen. In addition to the banded character of the ore, it seems evident there was a limited occurrence, closer to the surface, of nodular limonite and manganese oxide intimately mixed with yellowish-white clay and with black, manganiferous clay. The occurrence of manganese minerals associated with limonite at the Ironton pits is similar to their occurrence at other old iron ore pits in the Appalachian Valley.

Analyses of ore from the Ironton pits show that the "psilomelane type" lenses and bands were of good grade. The following analyses do not represent *average* Ironton ore.[96]

	1	2	3
Iron	2.562	—	26.4
Manganese	52.63	56.58	17.65
Sulphur	Trace	—	0.010
Phosphorus	0.63	Trace	0.095
Silica	4.85	—	—

The silica and phosphorus content is low and the manganese content of the first two analyses is excellent. However, the average manganese content of the ore from all the pits would probably be from one to five percent. The presence of 1.68 percent of cobalt in an analysis made by Genth in 1875 is significant. Also, the presence of 3.5 percent of K_2O and the small amount of BaO indicate the mineral is probably cryptomelane.

Because of the present condition of the properties, and its similarity to other known deposits in the Appalachian Valley, the possibility of achieving any significant manganese production from these pits seems unlikely. If there should ever be occasion to reopen the pits and the shaft, which is in one of the pits, for the iron ore, a complete investigation should be made of the relation between the manganese and iron ore, for there remains a real possibility that greater concentrations of manganese ore occur at depth. The old operations, at depths of 200 feet, did not reach the bottom of the clay, and only encountered the underlying limestone at one or two places.[97]

Wharton Mine (2)

One and a half miles southeast of Hellertown the Thomas Iron Company worked the Wharton mine for limonite ore until 1908. The ore lies immediately above the Hardyston quartzite. Mining opera-

[95] Miller, B. L., Manganese occurrences in eastern Penna.: Penna. Topog. and Geol. Survey Bull. 47, p. 7, 1922.

[96] Samples analyzed: 1. Average sample, analyst, A. S. McCreath; 2. Picked specimen, analyst, Henry Pemberton, Jr.; 3. Average (iron) ore, wharf at Ironton R.R. Co. Mine 182, analyst, David McCreath. (Prime, F., Jr., op. cit., pp. 42-43.)

[97] Miller, B. L., op. cit., p. 6.

tions exposed many bands of good manganese oxide ore. The mineral was probably "psilomelane type." It is reported [98] that the ore maintained an average of two percent of manganese. An analysis of the good ore is in Table 10.

Mines near Emaus (3)

Prime[99] reports the presence of manganese oxide in one of the mines that is located northeast of Emaus along the slope of South Mountain. An examination of the mine dumps near Emaus revealed pieces of the limonite ore mixed with manganese ore. Psilomelane or cryptomelane is the ore mineral. Apparently the manganese oxide was present in most of the mines as thin beds and lenses in the mass of limonite ore, intimately mixed with the clay residual from the limestone and the shaly beds in the limestone. It occurs also in the ore as small veinlets, and in some of the clay as nodules. A few small nodules of the ore were seen. An analysis of this ore is in Table 10.

Other Localities

Two other localities are mentioned by Prime[1] as having ores containing a high percentage of manganese. They are an old limonite mine one mile south of Alburtis (4), and another one mile south of Fogelsville (5). Analyses for both of these localities are presented in Table 10.

Table 10. Analyses of Lehigh County ore (in percent)

Locality	Manganese	Iron	Silica	Phosphorus	Sulphur
Wharton Mine ..	52.72	0.868	0.46	0.046	—
Emaus Mines ...	5.512	39.250	—	0.149	0.029
Alburtis Mine ..	9.280	44.50	—	0.316	0.019
Fogelsville Mine.	7.464	47.00	—	0.630	0.003

LYCOMING COUNTY

Slacks Run Area (1)

Specimens of manganiferous iron ore have been found near the mouth and along parts of the valley of Slacks Run near the village of Bodines in Cascade township (Warrensville sheet). The manganese and iron oxides have incompletely replaced sandstone that may be either Catskill or Pocono in age. The ore has retained the original texture of the sandstone, replacing the host rock grain by grain. The ore minerals are "psilomelane type" and limonite. Because the sandstone is irregularly and incompletely replaced, the ore minerals are very high in silica. If replacement were complete, the grade of the "ore" would be good.

The source of these specimens is undoubtedly from the plateau area drained by Slacks Run and underlain by both the Catskill and Pocono rocks. Manganese mineral occurrences like this may be expected at many places in the northern and western plateau counties of the State. On the basis of the evidence, there is little cause to

[98] Miller, B. L., op. cit., p. 5.
[99] Prime, Jr., Frederick, op. cit., pp. 27-29.
[1] Prime, op. cit.

think there may be deposits of the ore near the headwaters of Slacks Run. However, the possibility cannot be precluded without complete investigation of that area.

MONROE COUNTY

Tobyhanna Area (1)

Both wad and "psilomelane type" minerals have been found scattered in small quantities all over the plateau country around the headwaters of Bear Creek (Pocono sheet). The "psilomelane" is nodular, has a blue-black color, dark brownish-black streak, and a semi-conchoidal fracture. Manganese-bearing bogs on the plateau are probably the source of much of this scattered material. None of it is commercially important.

MONTGOMERY COUNTY

Small amounts of soft, black manganese oxide in gneiss have been noted at Spring Mill (1) (Norristown sheet) and at Edge Hill (2) (Germantown sheet). The wad lies in low swampy areas and covers the joint planes of near-by outcrops. It is in such small quantities that it has no commercial significance. The source of manganese has been chiefly the manganese-bearing garnet, spessartite, of the gneissic rocks.

Braunite and pyrolusite were reported from Edge Hill by Genth.[2]

NORTHAMPTON COUNTY

Manganese oxides occur in association with the Tomstown limestone of Williams and Saucon Townships (1) in Northampton County. Nodular "psilomelane type" minerals and pyrolusite, and soft structureless wad have all been found as sparsely scattered fragments in the residual clay of the Tomstown formation. There are no surface concentrations of this material to indicate a deposit at depth.

PHILADELPHIA COUNTY

Soft wad and a few nodules of "psilomelane type" minerals are scattered over low-lying surfaces in the gneiss area along Pennypack Creek (1) and near Bustleton (Germantown sheet). As with all other occurrences of oxides in the gneiss, the source of manganese is probably the manganese-bearing garnet, spessartite.

Genth[3] speaks of a bed of cobaltiferous manganese oxide in stratified drift opposite Fairmount Park (2) in West Philadelphia. The cobalt content was 10 percent. The exact location and thickness of the stratum is not known.

SOMERSET COUNTY

Near Hooversville a two-foot bed of iron carbonate ore, called the Hooversville iron ore, contains about one percent of manganese. It is unimportant for its manganese content.

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[2] Genth, F. A., The Mineralogy of Pennsylvania: Penna. 2d Geol. Survey, vol. B, p. 45, 1875.

[3] Genth, F. A., op. cit., p. 53.

SULLIVAN COUNTY

Dempsey Bog (1)

One mile northwest of Mildred in Sullivan County (Laporte quadrangle) a small bog, composed chiefly of wad, is located in a low-lying, swampy area adjoining Birch Creek on the farm of Mr. Pat Dempsey. In 1938 four random test holes were dug by Mr. Dempsey to a depth of 3 or 4 feet in the bog area; the holes were scattered sufficiently so that the area between them covered about one acre. Two of the holes penetrated bog manganese to a depth of 2 or 3 feet. The other holes showed evidence of some wad. During the summer months of 1941 two more holes were dug. One of these, 6 feet deep, is in the middle of the bog area; it showed no wad, only soft, dark brown earthy material underlain, at a depth of 6 feet, by a hard, plastic, bluish clay. The other hole, located within 5 feet of the small creek, was 4 feet deep and it penetrated no wad at all. Evidently, the occurrence is sporadic.

The manganese oxide occurs as soft, sooty, earthy matter completely impregnating a thin sandy loam. Most of it crumbles to the touch; locally it is fairly solid and assumes kidney shapes about the size of a large walnut. These kidney forms contain small amounts of limonite in irregular patches which apparently replace the manganese oxide. There is less than 10 percent of manganese in samples collected from the main mass.

Further prospecting by shallow pits placed about 25 feet apart, and in a grid pattern, would cost little and would definitely determine the presence or absence of a horizontal tabular bog. It has no value for its manganese content during normal times. It might be used as a filter for purifying gases.

Lopez Underclay (2)

Manganese oxide occurs as thin veinlets and as disseminated soft black wad in a four-foot bed of sandy underclay two feet beneath the middle coal of the Bernice coal field near Lopez (Laporte sheet). It colors the entire clay bed black. The areal extent of the occurrence is not known.

Microscopic examination of the mineral-bearing underclay (Lo-1) shows it to be composed of angular and sub-angular quartz grains ranging from .03 to .7 mm. in diameter and a small amount of sericite in tiny shreds and plates (pl. 25, B). About 10 percent of the volume is black manganese oxide. It occurs as a filling in and around the quartz grains, and apparently entered the clay along small distinct fractures which cut the mass. It raggedly replaces the larger quartz grains in the veined areas.

The source of the manganese is not known. Possibly some sedimentary manganese carbonate was deposited at the time the organic matter, which later formed the coal beds of the Bernice coal field, was accumulating. It is known that organisms contain manganese and influence its precipitation, though the extent of such influence is speculative.[4] Small amounts of manganese, as a carbonate, are known

[4] Zappfe, Carl, Deposition of manganese: Econ. Geol., vol. 26, pp. 799-833, 1931.
Bradley, H. C., Manganese in the tissues of lower animals: Jour. Biol. Chem. vol. 8, pp. 237-249, 1910.

to occur in iron carbonate beds of the Coal Measures in Somerset County.

The average content of manganese is less than five percent. The occurrence has no commercial importance.

SUSQUEHANNA COUNTY

White[5] mentions a large bog of wad ore near Great Bend (1) from which several tons of wad "were once mined and shipped on the Erie R.R." There are other small mixed iron-manganese bogs in the county. D. S. Harding[6] of Susquehanna, describes bog material, bearing manganese oxide, from two places about one mile southeast of the borough of Susquehanna (2). It consists of intimate mixtures of soft, earthy, brown, umber-like iron oxide and black wad and lies beneath 1½ feet of top soil. The depth and areal extent is not known. The manganese content of these bogs, and other small accumulations, is less than two percent. They have no commercial importance, other than possible use as a filtering medium for gases.

Chubbuck Property (3)

A manganese bog on the property of Theodore Chubbuck, five miles southeast of Thompson and two miles west of Mt. Ararat in Ararat township (Starrucca sheet) was sampled and analyzed: manganese 14.6 percent, iron 4.65 percent, insolubles 53.2 percent. The manganese content of this bog deposit is much better than most. The area occupied by the bog is approximately 400 feet long and 200 feet wide and the thickness of the bog ranges from two to five feet. It owes it origin to one, and possibly several, springs at an elevation of 2,050 feet that have spread manganese-bearing waters over the area floored by a nearly impervious glacial clay.

The manganese occurs as soft formless oxides and as small pellets of wad or pyrolusite, intimately mixed with rootlets and earthy material in the upper part of the bog and with considerable silica. Most of the manganese would be irrecoverable. For this reason and because of the small size of the deposit, there could be no commercial operation for its manganese. Possibly, this bog, as others, could be used for other purposes.

TIOGA COUNTY

Mansfield Area (1)

A small deposit of wad occurs two miles north of Mansfield, 100 feet above Kelly Creek along its south fork, and one mile east of its junction with Lambs Creek. An area 40 feet in diameter has been prospected by Mr. Wilfred Shaw, of Mansfield, owner of the property. The prospected area contains large blocks of coarse-grained, porous sandstone of the Chemung series that has been replaced by soft black manganese oxide. Some of the blocks consist of almost pure white to tan, even-grained sandstone with very slight impregnation by manganese oxide. Other blocks, within 5 feet, are almost completely replaced by the oxide and have the appearance of a hard white reticulate or skeletal pattern in a soft black background (pl.

[5] White, I. C., Geology of Susquehanna and Wayne Counties: Penna. 2d Geol. Survey, vol. G 5, pp. 93-94, 1881.

[6] Personal communication, April 1942.

10). Still other areas consist of massive, soft, black oxide without siliceous impurities.

Several smaller areas of similar character occur 5 to 10 feet higher along the slope. These small pockets are on a very gentle synclinal roll or flat. The beds normally dip 6°—8°N.W. The sandstone is underlain by thin-bedded, drab-green shale.

The deposit is of replacement origin. Manganese-bearing solutions moved down the dip of the beds at the contact of the porous sandstone and the relatively impervious shale and, where the solutions were partly ponded in the structural flat, the greatest amount of replacement took place. Where there is little or no replacement, the sandstone is impregnated and all of the pores are filled with the oxide. The source of the manganese is probably the Upper Chemung beds. A better than average sample, analyzed by the Pittsburgh Testing Laboratory, contained 5.04 percent of manganese. The grade of ore is too low to be commercially important, especially in view of its very high silica content. However, if large areas of completely replaced sandstone should be found, it might be used for the production of manganese metal despite the small percent of manganese.

VENANGO COUNTY

Victory Hollow Bog (1)

A large bog of mixed manganese-iron oxides occurs along the slope of the ravine made by Victory Run one mile south of its junction with Sandy Creek in Victory Township (Franklin sheet). The bog has an area of about 4 acres and is irregularly developed to thicknesses of 1 to 15 feet covering the slope from 1220 to 1280 feet elevation. The bog is actively forming by local deposition of iron and manganese oxides from springs and seepages.

Most of the bog consists of soft, earthy red and deep maroon iron oxide mixed with humus in its upper part. The manganese ranges from 0.2 to 1.5 percent. Locally the bog has a rust-yellow color and contains no manganese. The average thickness is about 3 feet.

The bog overlies a large talus slope composed of Shenango sandstone blocks, which form a more gentle slope than the valley wall. The top of the talus body is at approximately 1280 feet elevation. Surface and ground waters reaching the talus area are able to move freely and swifter through the jumbled blocks. Thus the waters are aerated and the iron and manganese, being carried in solution as the bicarbonate or carbonate, are oxidized and deposited in the talus area. Most of the openings between the talus blocks have been filled and the blocks covered, so that the waters now emerge at many places as seeps and springs and form large "mushy" areas of earthy iron and manganese oxide. Source of the manganese and iron is most logically from the overlying Mercer iron carbonate ore horizon.

There is not enough manganese in the bog to be of importance for its metal content. This deposit could be used for filtering gases.

Half a mile south of the bog in Victory Hollow two smaller bogs of similar nature occur on opposite sides of the stream at an elevation of 1280 feet.

Brundred Lease Bogs (2)

Seven bogs, containing from 1.5 to a little more than 2 percent of manganese, occur on the lease of the Brundred Oil Company along Twomile Run, three miles southeast of Franklin (Franklin sheet). The bogs are small, averaging about 40 feet in diameter and one to three feet in thickness. Some are mottled red and black and others just red. All of them are earthy and loosely compacted. They occur at an elevation of about 1220 feet over an area one mile in extent. The constant elevation at which the bogs occur indicates a similar genetic relation and suggests they may have been formed at a time when the erosion cycle paused at this level.

The bogs have no commercial importance for their manganese content.

River Ridge Bogs (3)

Two bogs of red and yellow earthy matter, similar to those of the Brundred Lease, occur at an elevation of 1200 feet along the south side of the Allegheny River 2½ miles east of Franklin (Franklin sheet) on the River Ridge farm. They are located in the ravines of two small tributaries of the Allegheny River. Their manganese content is less than 2 percent.

Kennerdell Bog (4)

A large bog, located on the flat of the north side of the Allegheny River half a mile east of Kennerdell in Rockland Township, was worked at one time. It is reported to have had a small percentage of manganese.

Bullion Hollow Bog (5)

A large bog, similar in physical nature and genesis to the Victory Hollow Bog, occurs along the slopes of both sides of Bullion Run at elevations of about 1200 to 1260 feet one mile from the junction of Bullion Run and Scrubgrass Creek in Clinton Township (Franklin sheet).

Other Bogs (6, 7, and 8)

Three small bogs with a questionable manganese content occur in Cornplanter Township and Cranberry Township (Oil City sheet).[7]

WYOMING COUNTY

In southwestern Wyoming County, and extending into both Sullivan and Luzerne Counties, is a plateau called Dutch Mountain (1), which includes an area about 20 miles in diameter. The topography, which is gently rolling and swampy, is controlled by the nearly horizontal underlying thick Pocono sandstone. In and near many of the swamps are bogs. Some of these bog areas are extensive; others are small. Many of them contain a small percentage of iron and a few of them are typical of the bog iron ore deposits found throughout the northwestern part of the State. The presence of manganese oxide in these bogs is common. The amount of manganese oxide seen in the bogs, and in the bog material is very small, but there is a possibility that some of the bogs may contain a relatively high percentage of manganese. There is abundant surface evidence of manganese oxide

[7] Sherrill, R. E., Oral communication, August 1941.

in the area, especially along the streams. Almost every stream bed contains black-stained cobbles and pebbles; some of these are covered by a film of manganese oxide that can be rubbed off. The manganese is carried in solution, probably as manganese bicarbonate, and is precipitated as manganese oxide where the stream flows over pebbles and cobbles, thereby being aerated and oxidizing the contained manganese.

About one mile east of Ricketts, near the Sullivan County line (Laporte quadrangle), on lands under lease to Mr. Henry Schmid, of Wilkes-Barre, a test pit was sunk at one time to explore for manganese ore. A semi-consolidated bed of sand and gravelly material near bedrock was found to be cemented by black manganese oxide. The manganese oxide in the material was probably less than 5 percent, but the appearance was like that of a "vein" of "black sandy ore." All the joint and bedding surfaces of the Pocono sandstone nearby show staining by manganese oxide. This area is within one mile of a large swamp that is drained by Mehoopany Creek, flowing northeast, and smaller streams flowing south and southwest. The swamp may contain bog manganese. Several pieces of pyrolusite have been reported from this area, but the writer saw none.

The immediate origin of the manganese in this area seems to be from the upper part of the Pocono sandstone or from the overlying formations which have been eroded. Practically all of the manganese is present as (fig. 2): bogs lying in swampy areas on the flat tableland of Pocono sandstone, or as films and cementing material along joint and bedding surfaces in the Pocono sandstone and in pebbles in the streams.

There is abundant evidence of the presence of low grade manganese oxide; its occurrence in the area is sporadic, and it seems doubtful that any would approach a commercially profitable form. Cheap prospecting by pits in some of the swampy areas may reveal relatively rich bog ore and this possibility should not be overlooked. Likewise, there is a possibility that some horizon in the Pocono sandstone is structurally favorable to the precipitation of manganese oxide from downward percolating waters, and may have caused the accumulation of a large body of ore. The Pocono sandstone is well jointed in this area, thereby affording ready passage to downward-moving waters. However, so little is known of detailed structures, it is not possible to say where favorable conditions for ore accumulation may exist.

YORK COUNTY

Louis Delone Bank (1)

The old Louis Delone iron ore bank, about two miles southeast of Hanover (Hanover sheet), was operated about 1867, and produced manganiferous iron ore that contained up to 7.29 percent of manganese.[8] The bank has since been filled in and the location is occupied by a cemetery. The associated rocks are the Ordovician limestones.

[8] Frazer, P., Jr., Report of progress for York and Adams Counties: Penna. 2d Geol. Survey, vol. C, p. 41, 1874.

Haldeman and Bechtel Banks (2)

Iron oxide with small amounts of manganese oxide was mined for many years from banks two miles northeast of Hanover and one mile west of Mt. Carmel Church. Frazer reported analyses showing 3 to 5 percent of manganese.[9] The two banks (50 by 40 feet and 260 by 50 feet) are now filled with water. No manganese oxide was found on the old dumps. These pits are in residual yellow clay weathered from the Conestoga limestone.

Smyser Bank (3)

Sixteen percent of manganese was reported associated with the iron ore at the Smyser ore bank, one mile east of Myers Mill, by Frazer.[10] The pit now filled with water, is 250 feet long and 75 feet wide. At the eastern end is a large dump that contains very little ore.

The iron ore occurs as two kinds of iron oxide, an early generation of rust-colored oxide, and a later generation of dark brown and black oxide which has almost completely replaced the former (Sm-1). The texture of the black oxide is dense in comparison with a porous texture for the rust-colored oxide. Associated with the black oxide, and cutting it as small veins in the central part of the black oxide areas is manganese oxide. The manganese mineral is psilomelane or cryptomelane.

The ore mass is a replacement concentration in residual clay weathered from the Vintage dolomite or the Conococheague limestone which bear a complex faulted relation to each other and to the Antietam sandstone at this locality. Source of the manganese and iron was probably the same, but is not known. Downward-moving waters carrying first iron, then iron and manganese together, replaced the kaolinitic matter and unweathered sericite, which comprise most of the clay, and part of the quartz. Very little quartz is in the black iron oxide that is near the manganese oxide, and none is in the manganese oxide.

The Smyser bank is typical of most of the old Valley iron ore pits in the mode of occurrence and the type of ore. Why there was more manganese mineralization at this locality than at some of the others is purely speculative. That the source was not uniform for all of these pocket-like ore deposits seems to be the best explanation.

There is no indication that the grade of the ore at the Smyser Bank averaged 15 percent of manganese; the locality is not considered to have any commercial importance.

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[9] Frazer, P., Jr., op. cit., p. 61.
[10] Frazer, P., Jr., op. cit., p. 67.

SUMMARY AND CONCLUSIONS

Superficial manganese mineralization is widespread in the State of Pennsylvania. Supergene replacement deposits and minor concentrations of manganese oxide minerals at 12 different stratigraphic horizons are controlled by structural, stratigraphic, and physiographic features. Significant mineralization is limited to three horizons, the basal Tomstown formation and basal Gatesburg formation of Cambrian age and the basal Mauch Chunk formation of Mississipian age. Possible commercial accumulations are at three localities, in the basal Mauch Chunk shale of Sherman Valley, Bedford County, and the basal Tomstown formation at Reading Banks and at White Rocks near Boiling Springs, Cumberland County.

Manganese mineral concentrations at the base of the Cambrian Tomstown formation throughout the length of the Great Valley in Pennsylvania are a northward extension of similar well-known concentrations at the base of the Shady dolomite and correlated formations from Pennsylvania to Alabama and Georgia. The presence of manganese oxide minerals in significant quantity at the Mauch Chunk horizon, however, has not been previously recognized. They may prove to be abundant and widespread in occurrence.

Cryptomelane, a newly named manganese oxide, is the most abundant manganese mineral in the State. Other associated supergene manganese oxide minerals include psilomelane, pyrolusite, manganite, and wad. All important accumulations of manganese oxides are closely associated with iron oxides. The exact source of manganese and iron in the deposits is not known in most cases.

Paragenetic study of the ores indicates manganese oxides are younger than iron oxides, replacing them and filling fractures in them. Recurrent stages of superficial mineralizing solutions often confuse this simple relation and revise the order.

A critical study of the Pennsylvania manganese oxide minerals by physical, chemical, optical, and X-ray methods shows that exact identification of the manganese oxides is not simple:

1. Correlation of the data of all four methods of examination is preferable for exact identification.
2. Etching tests are too variable, because of widely varied physical properties, to have more than contributory and possibly confirmatory determinative value.
3. Optical data alone are not dependable, except possibly for individual localities after correlation with X-ray determinations.
4. Correlation of X-ray and optical data alone is sufficient, in most cases, for exact identification.

Physical properties, such as grain size, absorbed water content, hardness, and others, influence the optical properties and etching reactions; the mutual relations and influence of these factors is a major unsolved problem.

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APPENDIX

Description of Polished Sections and Thin Sections

Reading Banks

B.S.-1a. Middle of ore face, north side of open cut.

Massive and dense, hard siliceous brown iron oxide, cut by small veinlets of black iron oxide and hard steel-blue manganese oxide.

Microscopic description (polished section). Minerals are rust-colored limonite, dark brown and black limonite, cryptomelane, and quartz.

Rust-colored limonite: poor polish, low reflectivity, "pocked" surface due to small locked-in quartz grains, no pleochroism or anisotropism, fairly strong internal reflection, hard.

Dark brown and black limonite: light grey on polished surface, medium reflectivity, hard, faintly anisotropic with two extinctions and polarization colors of shades of dark grey, no internal reflection or pleochroism, very few cracks.

Cryptomelane: white, high reflectivity, excellent polish, few cracks, extinction in 2°-3° position, deep lavender color under x-nicols, isotropic, hard.

Quartz: clear, unstrained, angular, average diameter of .05 mm., comprises 3 percent of section.

Main texture is result of replacement of quartz by limonite. Some colloform banding in veins.

Sequence of events interpreted from this section is:

1. Rust-colored limonite replaced clay matrix completely, leaving small, unreplaced quartz grains.
2. Movement of mass, causing fracturing of limonite.
3. Replacement by dark brown and black limonite.
4. Contemporaneous with, and later than No. 3, replacement by veins and disseminated blebs of cryptomelane.

B.S.-1b. Ten feet above bottom of ore face, north side open cut.

Massive, dense, hard siliceous brown iron oxide, cut by small veinlets of darker iron oxide and light blue manganese oxide.

Miscroscopic description (polished section). Three ore minerals present are rust-colored limonite, dark brown and black limonite and cryptomelane (fig. 5). The description of these minerals, and of the quartz grains which are mainly in the rust-colored limonite, are the same as for B.S.-1a.

Small irregular areas of incompletely replaced arenaceous clay are present.

Main texture is an irregular replacement of small veinlets and irregular masses.

Sequence of events interpreted from this section is (pl. 11, A):

1. Replacement of arenaceous clay by rust-colored limonite.
2. Fracturing of the mass by movement.
3. Secondary mineralization by contemporaneous dark brown and black iron oxide and manganese oxide; replacement by these in vein form. Manganese oxide is last, cutting some veins of dark limonite.

B.S.-2. From stock pile, one mile west of open cut.

Dense, siliceous brown iron oxide, covered with and replaced by irregular areas of black iron oxide and steel-blue manganese oxide.

Microscopic description (thin section). The minerals and their mode are iron oxide, 80 percent; goethite, 2 percent; manganese oxide, 8 percent and quartz, 10 percent.

Quartz is euhedral and subhedral, showing a number of hexagonal basal sections, clear, unstrained, averaging 0.2 mm. in diameter and ranging up to 1 mm. containing few inclusions of unidentifiable carbonate, cracked and brecciated, partly replaced by iron oxide.

Iron oxide has deep red-brown color, "shagreen" surface mainly due to small unreplaced quartz grains, no pleochroism or anisotropism.

Goethite is golden brown, finely prismatic crystalline and vertical to colloform bands, faintly pleochroic, isotropic, concentric structure.

Manganese oxide is black; no other properties can be observed, except colloform banding.

Irregular replacement relations between the different oxides and the quartz characterize the section.

Sequence of events interpreted from two thin sections (fig. 22, A):

1. Brecciation of Antietam quartzite.
2. Early iron oxide replaced all of the original clay matrix and part of the quartz, and filled fractures in quartz.
3. Fracturing of the mass.
4. Further replacement of the quartz and limonite by veins and irregular masses of manganese oxide and probable partial solution of some limonite.
5. Replacement of earlier iron and manganese oxides by colloform banded and crystalline goethite.

B.S.-3a. From stock pile, one mile west of open cut.

Dense, siliceous brown iron oxide with semi-conchoidal fracture, several cavities into which stalactites of the iron oxide have grown.

Microscopic description (polished section). The minerals are iron oxide (limonite) and quartz. Less than 10 percent of the section is quartz.

Limonite: poor polish, low reflectivity, hard, isotropic non-pleochroic; replaces quartz.

Quartz: fairly clear, sub-rounded to sub-angular, averaging 0.025 mm. in diameter.

Texture irregular, formed by replacement of the clay and relatively little replacement of the quartz by limonite.

B.S.-3b. From stock pile, one mile west of open cut.

Dense, siliceous brown iron oxide with irregular replaced areas of blue manganese oxide and veins of darker iron oxide and manganese oxide.

Microscopic description (polished section). Four minerals are present: rust-colored limonite, dark brown and black limonite, cryptomelane, and quartz.

Rust-colored limonite: same rusty color on polished surface, medium polish, low reflectivity, internal reflection, isotropic, non-pleochroic, hard, few cracks, abundant unreplaced quartz.

Dark brown and black limonite: light grey on polished surface, medium reflectivity, extinction in 2°-3° position, no internal reflection, non-pleochroic, weakly anisotropic, showing 2 extinctions and polarization colors of deep grey shades, no cracks.

Cryptomelane: white with a tint of yellow, very high reflectivity, excellent polish, non-pleochroic, isotropic, no internal reflection, extinction in 2°-3° position, deep lavender color under x-nicols.

Quartz: clear, sub-angular to angular, unstrained, averaging .03 mm. in diameter.

Texture chiefly colloform in cryptomelane and in dark limonite, both of which occur as irregular replacements. Botryoidal structure of cryptomelane well developed.

Sequence of events interpreted from the section:

1. Rust-colored limonite replaced the arenaceous clay, except for the quartz, which is relatively unreplaced.
2. Dark brown and black limonite replaced the mass by small veinlets and irregular, colloform-banded areas.
3. Cryptomelane replaced both stages of limonite, sometimes along the replacement contact of the two, also irregularly as colloform-banded veinlets and botryoidal masses (pl. 11, B and 12, A).

B.E.-4. From basal clay at bottom of open cut near north ore face.

Coarse-grained, brecciated Antietam sandstone, thoroughly cemented by iron oxide, now weathered light brown; cavities lined with black oxide. Specimen has a gossan-like character.

Microscopic description (thin section). Quartz, iron oxide, and manganese oxide are the minerals.

Quartz shows evidence of brecciation and mylonitization, occurring as elongated, sheared stringers closely bound together, making a gneissic appearance. Also later, clear, white, unstrained quartz.

Iron oxide: deep brown, irregular surface, isotropic, non-pleochroic, colloform banded, replaces and fills fractures in quartz.

Manganese oxide: black, colloform banded, isotropic.

Main texture created by gneissic character of quartz and by colloform banded concentric deposition of iron and manganese oxides in cavities in the quartz.

Sequence of events interpreted from the section (fig. 22, C):

1. Brecciation and mylonitization of the Antietam sandstone.
2. Filling of brecciated sandstone by contemporaneous iron and manganese oxides which deposited concentric and alternate bands of mineral matter in cavities. Partial replacement of quartz during filling of cavities.

B.S.-5. From ore face on north side open cut, 20 feet above floor.

Massive bedded mixed iron and manganese oxide ore with cavities and well developed botryoidal surfaces; dense brown and steel-blue, hard ore.

Microscopic description (two polished sections). Minerals are rust-colored limonite, dark brown and black limonite, cryptomelane, quartz, and zircon.

The descriptions of both kinds of limonite and of cryptomelane are the same as those of specimen B.S.-3b.

Quartz: clear, a few grains slightly strained, showing 2V of about 3°; sub-angular, averages 0.03 mm. in diameter, associated almost entirely with rust-colored limonite.

Zircon: two grains noted, rounded and pitted.

Colloform banding in veined areas of both cryptomelane and dark limonite forms the most striking texture. Irregular massive and veined replacement of early-stage limonite and quartz forms the main texture.

Sequence of events interpreted from two polished sections (pls. 12, B and 13):

1. Mineralization by solutions depositing rust-colored limonite which replaced basal clay of Tomstown formation, except for small, sub-angular quartz grains.
2. Limonite mass fractured.
3. Contemporaneously: a. Replacement by dark limonite of the rust-colored limonite, completely in some places and less in others, making an intimate mixture of the two. Also replacing cryptomlane selectively along colloform bands or veins. b. Replacement of rust-colored limonite and darker limonite, and probably of quartz, by veins of cryptomelane.

B.S.-6. From stock pile, one mile west of open cut.

Massive brown iron oxide with stalactitic growths on one surface.

Microscopic description (polished section). The only mineral is dark brown limonite. Polished surface: grey, medium reflectivity, isotropic, non-pleochroic, extinction in 3° position, no internal reflection, hard, radial cracks, colloform banding.

Main texture due to concentric colloform bands in the circular stalactitic growths. Many of these show excellent radial cracks, probably formed as the result of shrinkage of a gel during solidification.

Sequence of formation of colloform banding and stalactites well shown (pl. 14):

1. Newly forming stalactites consist of concentric cylindrical "sheets" of iron oxide joined by "supports" of the iron oxide at different intervals.
2. When the stalactites are 2-3 mm. in diameter, the separated "sheets" coalesce.
3. When they are 3-5 mm. in diameter coalescence is complete and the former structure is gone.
4. Other stalactites begin forming in the intervening spaces between two coalescing stalactites.

B.S.-7. From the ore face on south side of the open cut.

Massive, dense, siliceous brown iron oxide ore.

Microscopic description (polished section). Rust-colored limonite, dark brown and black limonite, and quartz are the minerals.

Quartz: clear, sub-rounded to sub-angular, some euhedral grains, averaging 0.1 mm. in diameter. Replaced by rust-colored limonite but never by darker limonite.

Rust-colored limonite is present as small irregular unreplaced fragments. Rusty colored, medium to low reflectivity, strong red-orange internal reflection, isotropic, non-pleochroic, hard, cracks. It forms about 70 percent of the section.

Dark brown and black limonite: grey, medium reflectivity, fair polish, very faintly anisotropic with black to dark grey polarization colors, no internal reflection, extinction in 2°-4° position, hard, non-pleochroic, no cracks.

Mottled texture is the result of partial replacement of quartz by rust-colored limonite and, in turn, partial replacement of it by the darker limonite.

Sequence of events interpreted from this section:

1. Replacement of arenaceous clay at base of Tomstown formation by rust-colored limonite with only partial replacement of quartz.
2. Minor fracturing.
3. Replacement and filling of fractures by darker limonite. No replacement of quartz.

B.S.-8. From the ore face north side of open cut, at level of old drift.

Bedded, brown and black, cellular iron oxide ore.

Microscopic description (polished section). Minerals are quartz, dark brown and black limonite, and cryptomelane.

Quartz is present to extent of less than three percent. Variable in size, ranging from 0.02 mm. to 0.1 mm. in diameter, clear, unstrained, and sub-rounded to sub-angular.

Dark limonite: light grey, medium reflectivity, hard, extinction in 2°-3° position, isotropic, non-pleochroic, no internal reflection, some cracks.

Cryptomelane: white, high reflectivity, hard, extinction in 2°-3° position, isotropic, non-pleochroic, deep lavender color under x-nicols, no internal reflection, few cracks.

Texture mainly colloform, botryoidal structures in the cryptomelane, and some stalactitic structures have resulted from the concentric colloform banded growth.

Sequence of events interpreted from this section (pl. 15, A):

1. Replacement of the arenaceous clay at the base of the Tomstown formation by cryptomelane in irregular masses and veins.
2. Fracturing of the ore mass.
3. Replacement and fracture filling by dark limonite.

B.S.-9. From basal clay near bottom of open cut along north ore face.

Massive brown and steel-blue ore containing brecciated quartzite and vein quartz fragments, having an irregular mottled appearance because of different relations of iron and manganese oxides as replacements and fracture fillings. The surface of several fractures is covered with soft black velvety manganese oxide that rubs off easily.

Microscopic description (thin section). Minerals are quartz, zircon, iron oxide, manganese oxide, and yellow clay.

Quartz: vein quartz and quartzite fragments, shattered into tiny pieces averaging 0.02 mm. in diameter. Larger grains of quartz, 1 mm. and more in diameter, are rounded and partly replaced in contrast to angular, unreplaced small fragments. They also contain small carbonate inclusions.

Zircon: present as an accessory residual mineral from the replacement of the clay.

Iron oxide: deep reddish-brown, isotropic, non-pleochroic, occurs as veins and anastomosing veinlets and irregular areas.

Manganese oxide: black, isotropic, non-pleochroic, occurs as veins.

Main texture is mottled, created by many angular pieces of quartz in embodying iron oxide. Veined texture in some parts of section is result of almost countless fine veinlets of manganese oxide cutting across iron oxide and quartz.

Sequence of events interpreted from this section (fig. 22, B):

1. Brecciation of quartzite (probably Antietam).
2. Replacement of the clay by iron oxide.
3. Further fracturing of the ore mass.
4. Replacement of iron oxide and, to a very small extent, the quartzite by manganese oxide. Filling of fractures in the quartz. Mixing of iron and manganese oxides along the main manganese oxide veins.
5. Contemporaneous with No. 4, deposition as thin colloform banded layer, golden colored iron oxide in the main vein of manganese oxide.

B.S.-9a to 9d. From basal clay near bottom of open cut along north ore face.

Brecciated quartzite (pure white and vitreous) has been impregnated with hard, siliceous, brown limonite, having a cherty appearance locally. Well defined veinlets of black manganese oxide cut the limonite and follow fracture planes in the limonite and quartz.

Microscopic description (4 polished sections). Minerals present are quartz, rust-colored iron oxide, dark brown and black iron oxide, cryptomelane, manganite, pyrolusite.

Quartz: fragmentary vein and quartzitic material, averages about 0.02 mm. in diameter, strained, clear, angular.

Rust-colored limonite: dark grey, occurring in small, irregular grains, clusters, and masses, all replacement remnants. Medium reflectivity, hard, no complete extinction, strong internal reflection, non-pleochroic, cracks.

Dark brown and black limonite: occurs as irregular replacement masses and veins. Light grey, medium reflectivity, hard, extinction in 2°-3° position, dark grey with lavender tint under x-nicols, isotropic, non-pleochroic, no internal reflection, few cracks.

Cryptomelane: occurs as veins and small, disseminated lens-like patches. Yellow-white, medium high reflectivity, hard, extinction in 2°-3° position, color lavender under x-nicols, iostropic, non-pleochroic, no internal reflection, few cracks, excellent colloform texture.

Manganite occurs as coarse-grained veins, stringer veinlets, and clusters of radial prismatic crystals. Grey-white to grey, medium high reflectivity, hard, extinction at about 3° position, strong anisotropism with polarization colors of white, grey, violet, brown, and dark grey. Very weak pleochroism probably parallel to 010, few cracks, excellent colloform banding.

Pyrolusite: Pseudomorphous after manganite, may also have altered from cryptomelane; grey-white, high reflectivity, soft extinction in 2°-3° position, weak anisotropism with polarization colors of grey-white, black, and dark grey. non-pleochroic, no internal reflection

Texture of irregular replacement masses of dark brown limonite is mottled by included, unreplaced rust-colored limonite and quartz. Texture of veined areas is typically colloform.

Sequence of events interpreted from these sections (pls. 16, 17, and 18):

1. Brecciation of the Antietam sandstone.
2. Replacement of basal clay of Tomstown and filling of brecciated areas in the Antietam by rust-colored iron oxide.
3. Irregular replacement of the rust-colored iron oxide and partly of the quartz by large masses of darker iron oxide.
4. Replacement of the iron oxides, and of quartz to a less extent by veins, stringers, and small patches of cryptomelane.
5. Replacement of all the earlier minerals by veins of dark brown and black iron oxide. (Where No. 5 is present, there is not any No. 3).
6. Replacement of the earlier minerals by veins and stringers of manganite.
7. Alteration of manganite to pyrolusite, and of cryptomelane to pyrolusite and wad.

B.S.10. From prospect pit on north flank of South Mountain, half a mile north of White Rocks.

Nodular, black, concentric-banded manganese oxide ore.

Microscopic description (polished section). The only mineral in the section is cryptomelane. Grey-white, medium and high reflectivity, hard, extinction in 3°-5° position, pale lavender color under x-nicols, isotropic, non-pleochroic, no cracks, no internal reflection.

Texture is colloform. Banding is parallel to the large concentric circular structure which makes the nodular form (pl. 19, A).

B.S.-11. From surface, 100 yards south of the open cut.

White to grey, medium-grained, dense quartzite with a small amount of black manganese oxide replacing the very edges of the specimen.

Microscopic description (thin section). Quartz is the main mineral; minor amount of black manganese oxide occurs as a coating on the grains.

Quartz: both clear and stained by oxides of manganese. Sub-rounded elongate shapes, some grains strained, showing 2V of about 3°, averaging 0.1 to 0.2 mm. in diameter.

Manganese oxide: black and filmy.

Texture of quartzite formed by elongated quartz grains, closely packed, lying parallel to bedding (pl. 19, B).

Sherman Valley

H-1. From top ore bed in face of open cut.

Dense, massive and botryoidal steel-blue manganese oxide ore; botryoids mainly confined to "split" areas in the mass. Breaks with semi-conchoidal fracture and has a sub-metallic luster.

Microscopic description (polished section). Minerals are cryptomelane, quartz, and wad.

Cryptomelane: yellowish white, high reflectivity, hard, extinction in 3° position, deep lavender color under x-nicols, isotropic, non-pleochroic, no internal reflection, few cracks, practically no colloform bands.

Quartz: uniform sized, about 0.09 mm. in diameter, sub-rounded, dark-grey, clear, strong internal reflection.

Wad: black, porous; other properties non-measurable.

Texture is varied. In some areas, concentration of unreplaced quartz grains makes a mottled texture. An irregular area of intersecting and interlocking dendritic branches of the mineral forms a distinctive texture—this corresponds to silvery prismatic crystalline areas seen megascopically on some specimens from the ore face. Rare development of colloform texture and botryoidal structure in this section.

Sequence of events interpreted from the section (pl. 20, A):

1. Replacement of red shale shown by embayment and penetration of shale area by cryptomelane.
2. Unreplaced quartz grains oriented parallel to edge of shale by the mineral-bearing solutions during the process of replacement of the shale.
3. Alteration to wad along few cracks.

H-2a. From near top of upper ore bed, face of open cut.

Dense, massive and botryoidal blue-black manganese oxide ore with large opening in center of two-inch "bed" into which botryoidal oxide extends.

Microscopic description (polished section). Minerals are cryptomelane and quartz, and the descriptions are the same as for H-1.

Botryoidal structures and good colloform texture characterize the section. Small areas of radial, prismatic crystalline forms are also cryptomelane and correspond to one of Schneiderhöhn's "components" of psilomelane.

There may be two generations of cryptomelane (pl. 20, B). Different parts of the section have slightly variable properties of color and reflectivity. Because there is no clear evidence for a later generation of cryptomelane, the differences may only be the result of slight compositional changes in the mineral-bearing solutions during their deposition in a gel-like state.

H-2b. From top ore bed in face of open cut.

Microscopic description (polished section). Minerals are quartz and two phases (or generations) of cryptomelane.

Quartz: sparsely scattered through section. Uniform, sub-rounded grains, averaging 0.08 mm. in diameter, clear, dark grey, showing strong internal reflection.

Cryptomelane differs in the two phases only with respect to hardness, color and reflectivity. (Both are cryptomelane as proved by X-ray identification.) The one is white, hard, with very high reflectivity; the other yellowish white, not as hard, and with lower reflectivity (still high!). The latter comprises 70 percent of the section. Both have excellent colloform banded area. Doubtful evidence indicates the latter mineral is a selective replacement of the former along certain colloform bands.

H-3. From small dump across road from open cut.

Bedded, dense, blue-black manganese oxide ore with some botryoidal surfaces and softer, black zone in the middle.

Microscopic description (polished section). Minerals are two generations of cryptomelane, pyrolusite and quartz.

Cryptomelane: white, high reflectivity, hard, extinction in 2°-3° position, isotropic, non-pleochroic, no internal reflection, color lavender under x-nicols, few cracks; occurs dominantly as botryoids with good colloform banding.

Pyrolusite: black, sooty, finely matted, and with a dendritic crystalline growth; no polish, very low reflectivity, soft, isotropic, non-pleochroic. Grades into cryptomelane from a central zone.

Quartz: occurs as scattered, unreplaced, sub-rounded, clear grains, strong internal reflection.

Texture mainly colloform, giving rise to excellent botryoidal structures.

Sequence of events interpreted from this section (pl. 21).

1. Replacement of shale by cryptomelane.
2. Deposition of second generation cryptomelane as growth caps on botryoids of first generation cryptomelane, with a resorption or "reaction" rim, brilliantly white and very highly reflective between them.
3. Alteration of central channel-like zone to pyrolusite by late solutions.

H-4 and H-7. From lower ore bed in face of open cut.

Massive brown and black, crudely bedded iron oxide ore.

Microscopic description (polished section). Minerals are cryptomelane, limonite, quartz, zircon, and red shale masses.

Cryptomelane: white, high reflectivity, hard, extinction in 2°-3° position, strong lavender color under x-nicols, isotropic, non-pleochroic, no internal reflection, cracks transverse to vein direction; occurs in reopened veins of limonite.

Limonite: light grey, medium reflectivity, hard, extinction in 2°-3° position, very dark violet-grey under x-nicols, isotropic, no internal reflection, few cracks, occurs as replacement in vein-form and larger irregular masses.

Quartz: making 30 percent of section, is sub-rounded, averages 0.03 mm. in diameter. Thousands of tiny quartz grains, almost beyond resolving power of microscope, are oriented parallel to colloform banding in limonite.

Zircon: grey with pitted surface and rounded shape, average of 3 grains 0.03 mm. in diameter.

Texture, colloform in veins of limonite and cryptomelane. Mottled texture results from unreplaced quartz in limonite all over section.

Sequence of events in this section (pl. 22 and fig. 21):

1. Replacement of arenaceous shale by irregular masses and veins of limonite, leaving quartz relatively unreplaced.
2. Slight movement causing opening of veins.
3. Replacement of shale and of irregular masses of limonite by cryptomelane and "filling" of reopened limonite veins by deposition of cryptomelane.

H-5. From ore face in open cut.

Crushed and washed ore.

Microscopic description (polished section). Minerals are cryptomelane, limonite, quartz, zircon, chalcopyrite, and wad.

Cryptomelane, limonite, quartz and zircon, have exactly the same descriptions as in H-4.

Chalcopyrite is present as a few rounded grains, evidently remnants of the replaced shale. Yellow, medium high reflectivity, soft, isotropic, non-pleochroic.

Wad, as soft, black, manganese oxide is an alteration product along the few cracks in cryptomelane.

Replacement veined texture, almost dendritic at some places due to anastomosing veinlets, characterizes individual crushed grains.

Fifty percent of the material is composed of clean, white grains of cryptomelane; the remainder is mixed with and replaced by small veinlets of limonite. The sequence is (pl. 23, A):

1. Replacement of impure arenaceous shale by cryptomelane, leaving unreplaced shale fragments, quartz, and chalcopyrite.
2. Replacement of cryptomelane by small, anastomosing veinlets of limonite.
3. Alteration of cryptomelane along cracks to wad.

H-6. From ore face in open cut.

Finely crushed and washed ore. Crushed to about 100 mesh.

Microscopic description (polished section). Minerals are two generations of cryptomelane, limonite, quartz, and chalcopyrite. Same description as for H-4.

Fine grains show botryoidal structure and colloform texture; complete botryoids are developed with a size of only 0.05 mm. diameter.

Second generation cryptomelane is "splintery" prismatic, surrounds first generation cryptomelane and even penetrates it (fig. 19). It is whiter and has a higher reflectivity.

Sequence of events interpreted from the section (pl. 23, B):

1. Replacement of arenaceous shale by limonite.
2. Partly contemporaneous cryptomelane, as shown by alternating bands with limonite. Cryptomelane also replaced limonite in vein form.
3. Second generation cryptomelane may be a late phase of solidification of the first generation material, with partial replacement of that material.

S.V.-9. From old mine slope and open cut, Sherman Valley.

Red shale (Mauch Chunk), thinly laminated, soft, and covered with films of manganese oxide on joint and bedding surfaces.

Miscroscopic description (3 thin sections). Minerals are quartz, sericite, iron oxide, and manganese oxide. Accessory zircon, small amount carbonate (calcite), kaolinite.

Mode of average shale.

quartz	40-45 percent
sericite	30-35 percent
limonite	15-20 percent
others	2+− percent

Percentage of replacing manganese oxide ranges from 0 to 80; showing 2V or 4° as an average, .02 to 0.1 mm. in diameter.

Quartz: fairly clear, sub-rounded to sub-angular, slightly strained, showing 2V of 4° as an average, .02 to 0.1 mm. in diameter.

The percentage of quartz in polished sections showing manganese ore, which has replaced red shale, is less than the percentage of quartz in the mode of the average shale, indicating replacement of some of the quartz by iron and manganese oxides.

Sericite: thin fibers and small plates up to 0.1 mm. long, usually aligned parallel to bedding; primary; where abundant and thickly matted, there is more iron oxide.

Iron oxide: primary; thin laminae of pure oxide show "contemporaneous deformation" (pl. 24, A). Deep brown, isotropic, non-pleochroic.

Manganese oxide: black, isotropic, non-pleochroic, occurs as replacement of everything except part of quartz.

Carbonate: (calcite) uncommon, rounded grains, averaging 0.1 mm. in diameter, excellent twinning, high birefringence and relief.

Zircon: grains rounded, very high relief, high birefringence, only a few grains present.

Kaolin: spotty, grain-like areas, indicative of former presence of feldspar. Amorphous grey-white mass, surface reflection.

Sm-1. From dump at edge of Smyser ore bank, one mile from Myers Mill, York County.

Fairly dense, rust-brown iron oxide cut by veinlets of black oxide.

Microscopic description (polished section). Minerals are rust-colored limonite, black limonite, cryptomelane, and quartz.

Rust-colored limonite: light grey-white, medium reflectivity, hard, extinction in 3° position, isotropic, non-pleochroic, faint internal reflection, few cracks, occurs as irregular mass.

Black limonite: grey, medium reflectivity, hard, extinction in 2°-3° position, isotropic, non-pleochroic, no internal reflection, few cracks, occurs as replacing veins.

Cryptomelane (?): white, high reflectivity, hard, extinction in 2°-3° position, color lavender under x-nicols, isotropic, no internal reflection, persistent cracks transverse to vein; occurs as vein in center of black limonite vein.

Quartz: clear, sub-angular, averages 0.02 mm. in diameter, makes 10-15 percent of section.

Texture open, almost mottled because of scattered unreplaced quartz grains.

Sequence of events interpreted from this section:

1. Replacement of arenaceous clay by rust-colored limonite.
2. Replacement of rusty limonite, and part of quartz by veins of black limonite.
3. Contemporaneous with No. 2, replacement by cryptomelane, making alternate bands with black limonite.

H.F. From a pit of old Huntingdon Furnace workings, Huntingdon County.

Dense, nodular, steel-blue, manganese oxide ore with a sub-metallic luster, brownish-black streak, and hardness 6 to 7.

Microscopic description (polished section). Mineral is cryptomelane in two generations.

First generation: grey-white, medium reflectivity, hard, extinction in 3° position, grey with purplish tint under x-nicols, isotropic, non-pleochroic, no internal reflection, many radial cracks.

Second generation: white, high reflectivity, hard, extinction slightly less than first generation, lavender under x-nicols, isotropic, non-pleochroic, no internal reflection, few cracks.

Texture typically colloform with well developed botryoidal structures.

Sequence of events interpreted from the section (fig. 25)

1. Replacement of clay by first generation cryptomelane, including any quartz that may have been in the clay.
2. Shrinkage of gel-like mass during solidification and development of radial cracks across colloform banding and concentric botryoidal structure.
3. Filling of cracks and possible partial replacement along them by second generation cryptomelane, which is also banded.

P-1. From edge of old Promise ore bank near Pond Creek, Franklin County.

Small nodules of dense brown and black oxide ore.

Microscopic description (polished section). Minerals are cryptomelane and pyrolusite.

Cryptomelane: white, high reflectivity, hard, extinction in 2°-3° position, lavender under x-nicols, isotropic, non-pleochroic, no internal reflection, cracks. Occurs as a band around a cavity in the pyrolusite and as small disseminated "specks" throughout the pyrolusite mass.

Pyrolusite: medium grey, low reflectivity, soft, extinction under full x-nicols, isotropic, non-pleochroic, no internal reflection. Occurs as replacement of siliceous iron oxide, retaining its texture.

Texture, porous and granular, assumed from the former iron oxide and unreplaced quartz.

Sequence of events interpreted from the section:

1. Replacement of siliceous iron oxide by pyrolusite.
2. Almost contemporaneous with No. 1, but somewhat later, filling of cavities with blebs of cryptomelane, and bands of it where the cavity is large enough.

E-1. From yellow clay near bottom of English ore bank, near Pond Bank, Franklin County.

Massive brown and blue mixed iron and manganese oxide ore.

Microscopic description (polished section). Minerals are rust-colored iron oxide, black iron oxide, quartz and two generations of cryptomelane.

Rust-colored limonite: dark grey, medium reflectivity, hard, extinction in 2°-3° position, isotropic, non-pleochroic, weak internal reflection, few cracks, little of it remains in thin, strung-out patches.

Black limonite: grey-white, medium reflectivity, hard, extinction 2°-3° position, isotropic, non-pleochroic, no internal reflection, no cracks, irregular mass replacement occurrence.

Quartz: clear, sub-rounded, averaging 0.02 mm. in diameter, most abundant in the rust-colored limonite, lesser abundance in black limonite, absent in cryptomelane.

Cryptomelane: white, high reflectivity, hard, extinction in 3° position, lavender color under x-nicols, isotropic, non-pleochroic, no internal reflection, no cracks. The second generation material has a higher reflectivity. Occurs in veins replacing black limonite.

Texture is irregular replacement type.

Sequence of events interpreted from the section:

1. Replacement of arenaceous clay by rust-colored limonite.
2. Irregular replacement by black limonite of earlier limonite and partly of quartz.
3. Almost contemporaneous with No. 2, replacement by veins of cryptomelane of black limonite and quartz; and a second generation of cryptomelane filling center of first generation veins.

L.B.-1. From clay along top of old Laurel Banks near Pine Grove Furnace, Cumberland County.

Brecciated quartzite filled with dense black and brown, crudely bedded iron and manganese oxides.

Microscopic description (2 polished sections). Minerals are rust-colored limonite, black limonite, cryptomelane, and quartz.

Rust-colored limonite: dark dirty grey, poor reflectivity, hard, extinction under full x-nicols, isotropic, non-pleochroic, no internal reflection, cracks; most of it has been replaced, a few sheared remnants remain.

Black limonite: grey, medium reflectivity, hard, extinction at 3° position, isotropic, non-pleochroic, medium internal reflection due to included and unreplaced quartz, many cracks; occcurs as irregular replacement areas.

Cryptomelane: yellowish white, high reflectivity, hard, extinction in 2°-3° position, pale lavender color under x-nicols, isotropic, non-pleochroic, no internal reflection, few cracks, occurs as irregular and as veined replacements.

Quartz: clear and dirty, angular and sub-angular, strained and fractured, ranging in diameter size from 0.01 to 1 mm.

Texture is "gneissic" in appearance as result of elongated irregular replacement of rust-colored limonite by black limonite, and the orientation of quartz fragments in this direction. Iron oxide area is more or less porous and anastomosing manganese oxide veinlets cut this mass.

Sequence of events interpreted from the section.

1. Sandy clay, containing fragments of quartzite and vein quartz, replaced by rust-colored limonite.
2. Replacement of the mass by black limonite.
3. Shattering of mass, fractures throughout.

4. Infiltration of cryptomelane which irregularly replaced black limonite and filled all small cracks leaving isolated fragments of it, 0.05 mm. in diameter, in the manganese oxide.

W-1. From soft black clay at bottom of old Wharton pit, Cumberland County.

Soft, black, nodular manganese oxide ore.

Microscopic description (polished section). Minerals are pyrolusite and cryptomelane.

Pyrolusite: dirty grey, low reflectivity, soft, extinction under full x-nicols, weakly anisotropic with polarization colors in shades of grey, non-pleochroic, no internal reflection; ragged and porous character.

Cryptomelane: white, high reflectivity, hard, extinction at 3° position, lavender under x-nicols, isotropic, non-pleochroic, no internal reflection, cracked; raggedly altered and changed to pyrolusite.

Texture is granular-porous.

Sequence of events interpreted from the section (pl. 24, B):

1. Replacement of clay and Antietam sandstone by cryptomelane, both as an irregular replacement and as later veins.
2. Alteration of cryptomelane to pyrolusite, especially in irregular areas, less so in vein areas which have a denser texture.

Mc-1 and Mc-2. From pits of McCarrick prospect one mile west of Mt. Holly Springs, Cumberland County.

Nodular and crudely bedded black, siliceous manganese oxide ore, with some surfaces botryoidal and reniform, showing large unreplaced fragments of Antietam sandstone.

Microscopic description (2 polished and 1 thin section). Minerals are cryptomelane, pyrolusite, and quartz.

Cryptomelane: white, high reflectivity, hard, extinction at 2°-3° position, lavender color under x-nicols, isotropic, non-pleochroic, no internal reflection, few cracks.

Pyrolusite: dirty grey, low to medium reflectivity, soft, extinction under x-nicols, isotropic, non-pleochroic, no internal reflection, granular and porous in appearance.

Quartz: dirty, pitted, strained, showing 2V up to 5° (fig. 23), averages about 0.1 mm. in diameter; occurs scattered and, occasionally, in aligned zones parallel to colloform banding.

Texture in cryptomelane is colloform, and botryoidal structures are well developed. In the pyrolusite it is granular from the replacement of the quartz grains.

Sequence of events interpreted from the sections:

1. Replacement of sandy clay and brecciated Antietam sandstone by pyrolusite.
2. Replacement by cryptomelane of sandy clay and sandstone at other locations, probably contemporaneous with No. 1.
3. Alteration in zones of cryptomelane to pyrolusite. (An alternate interpretation could make No. 3 and No. 1 contemporaneous and both later than No. 2).

O-1 and O-2. From ledge of Oriskany sandstone, near portal of caved drift, northwest of Orbisonia, Huntingdon County.

Black, impregnated sandstone.

Microscopic description (2 thin sections). Minerals are quartz, manganese oxide, iron oxide, apatite and zircon.

Quartz: 80 percent of section. Fairly clear, sub-rounded, two uniform sizes—from 0.25 to 0.40 mm. in diameter and an average of 0.1 mm. in diameter. Sixty percent of grains are strained, showing 2V up to 3° or 4°. Contain inclusions of very small apatite and zircon, and some carbonaceous matter.

Iron oxide of two types: an early golden-colored type, rounded, isotropic, non-pleochroic; a later type, light yellow, isotropic, non-pleochroic, which partly replaces quartz. Both are uncommon, making less than 5 percent of section.

Manganese oxide: black, soft, granular-appearing, completely filling all space between quartz grains and raggedly replacing the edges of the strained grains. Fills fractures in all the grains.

Texture is granular, that of the original sandstone.

Sequence of events interpreted from the section (pl. 25, A):

1. Impregnation of Oriskany sandstone and very minor replacement of some of the sand grains by iron oxide.
2. Later impregnation and replacement of most of the iron oxide by manganese oxide, and partial replacement of quartz grains by manganese oxide.

Lo.-1. From underclay of middle coal in Bernice coal field, near Lopez, Sullivan County.

Massive, dark grey, arenaceous clay.

Microscopic description (thin section). Minerals are quartz, sericite and manganese oxide.

Quartz: comprises 80 to 90 percent of the section. Few clear grains, most streaked with oxide, angular and sub-angular, range from 0.03 mm. to 0.7 mm. in diameter, secondary growth of quartz on some edges; small grains form a matrix for larger grains. Few unidentifiable inclusions in larger grains. Ragged edges partial replacement.

Sericite: thin shreds and plates make one percent of section.

Manganese oxide: black, impregnates all pore space of section, may have replaced some sericite (no evidence for it), raggedly replaces the edges of quartz grains along a vein of the oxide (pl. 25, B).

Texture that of a loosely packed sandstone cemented by manganese oxide.

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PLATES

A. Northeast entrance to the Sherman Valley open cut (looking southwest).

B. Ore face of the Sherman Valley open cut. Crutches mark position of high grade (left) and low grade (right) "beds" of ore (looking northeast).

A. High-grade "bed" of manganese oxide ore essentially parallel to beds of Mauch Chunk shale; ore face of Sherman Valley open cut (looking northeast).

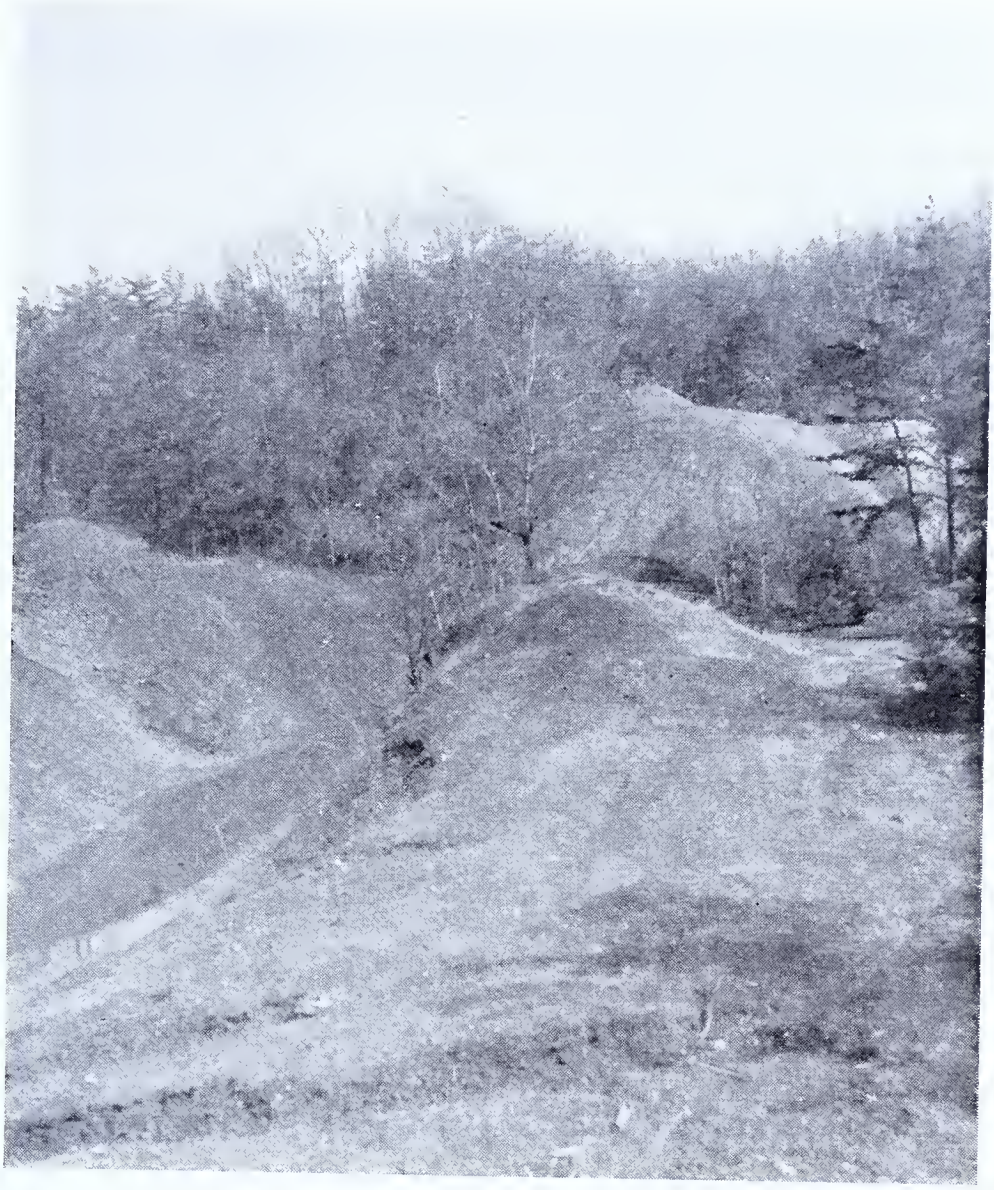
B. Floor of Sherman Valley open cut. "X" marks the outcrop of low-grade ore which dips to the right. Waste material at right overlies old mine slope (looking southwest).

A. Mauch Chunk red shale dipping northwest in side of Sherman Valley open cut (looking southwest).

B. Well developed joints in the Mauch Chunk red shale. "A", longitudinal joint (N. 65° E); "B", cross joint (N. 15° W). Old mine slope in foreground (looking northwest).

Boiling Springs Furnace. This furnace was used to smelt the ore from Reading Banks, two miles southeast of the town, and from many other mines throughout the Cumberland Valley.

Plate 6



A. Reading Banks, originally called Ege Bank. Water-filled part is bottom of old workings. Waste clay is dumped to right and left.

B. Mauch Chunk red shale from Sherman Valley, Bedford County. Top bed is coated with film of manganese oxide along the joint plane.

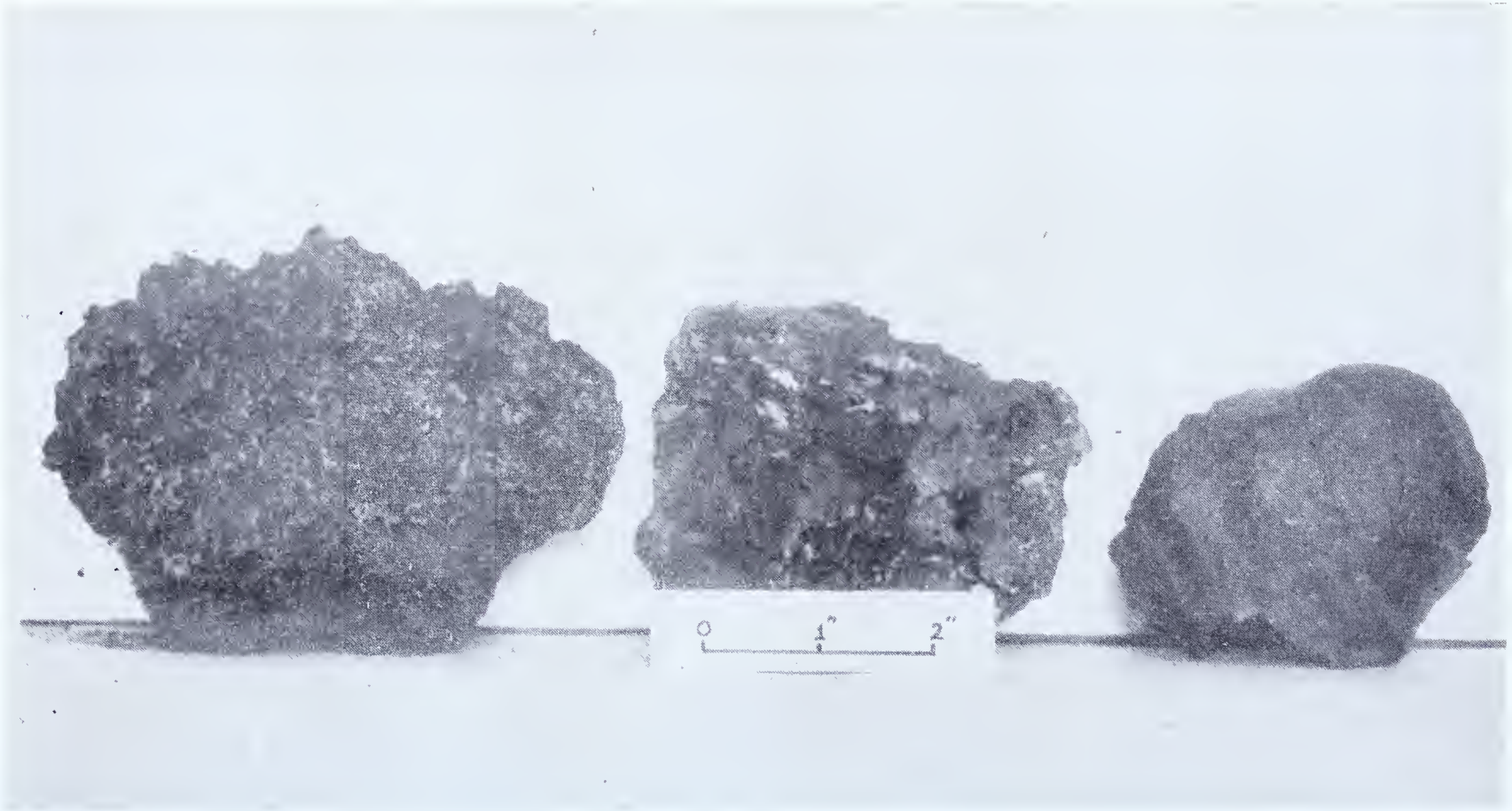
Plate 7

A. Reading Banks (old Ege Bank), looking west. Note the ore in place in right center. Deepest part of workings were here, about 70 feet below the top of the bank.

B. Mixed manganese-iron oxide ore from lower ore bed of Sherman Valley open cut.

A. Cryptomelane from ore bed of Sherman Valley open cut.

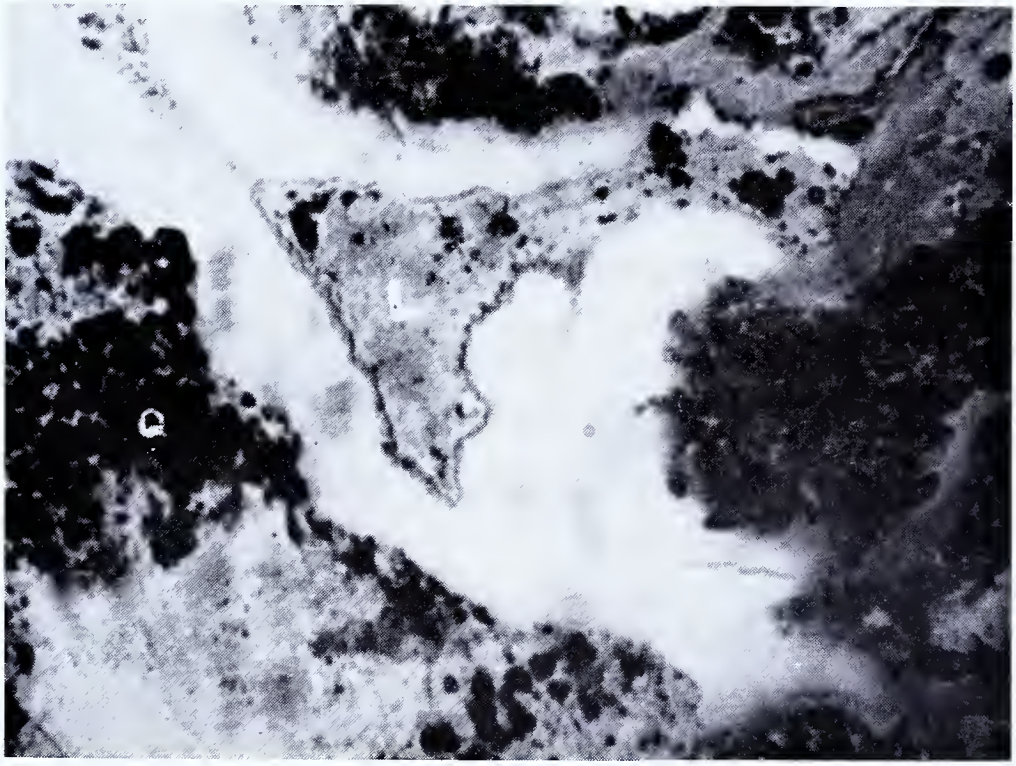
B. Manganese-iron oxide from Reading Banks. Note unreplaced, brecciated fragments of Antietam quartzite.



Left: Mansfield ore. Soft, black manganese oxide replacing Chemung sandstone. Notice the network of unreplaced silica.
Center: Brecciated Antietam sandstone cemented by iron oxide. Reading Banks.
Right: Nodule of cryptomelane from near Reading Banks.

Plate 10

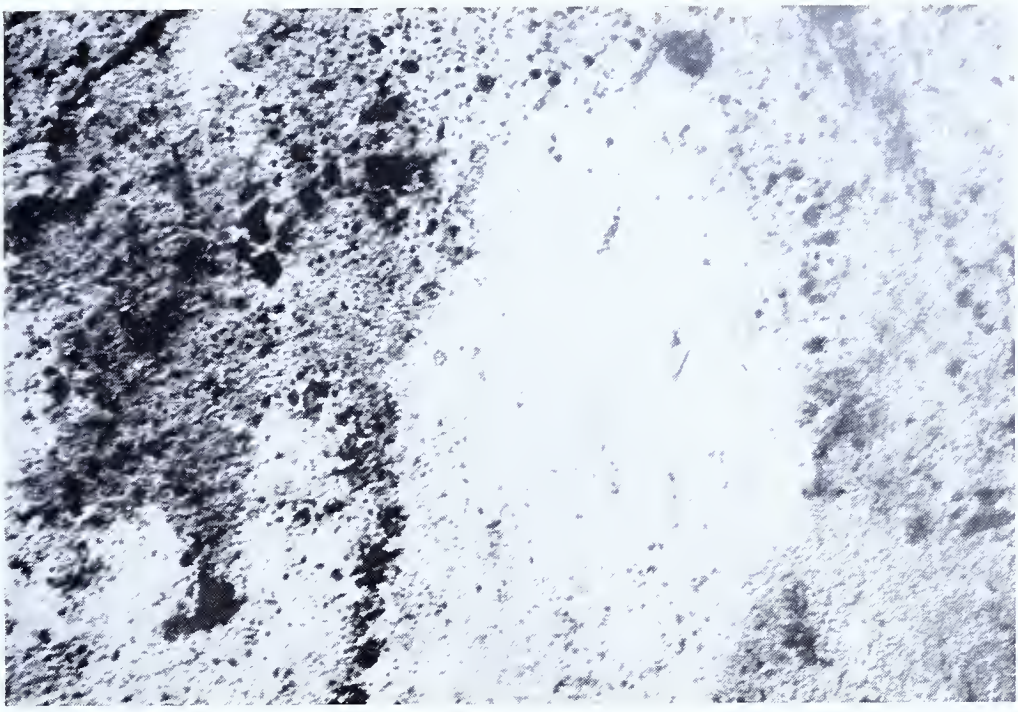
A. Clay, "cl", surrounded and replaced by black limonite (light area). Dark grey and black area is mixed quartz and rust-colored limonite, both replaced by black limonite. Cryptomelane "P", replaces black limonite. (Magnification 75X. Specimen B.S.-1b.)



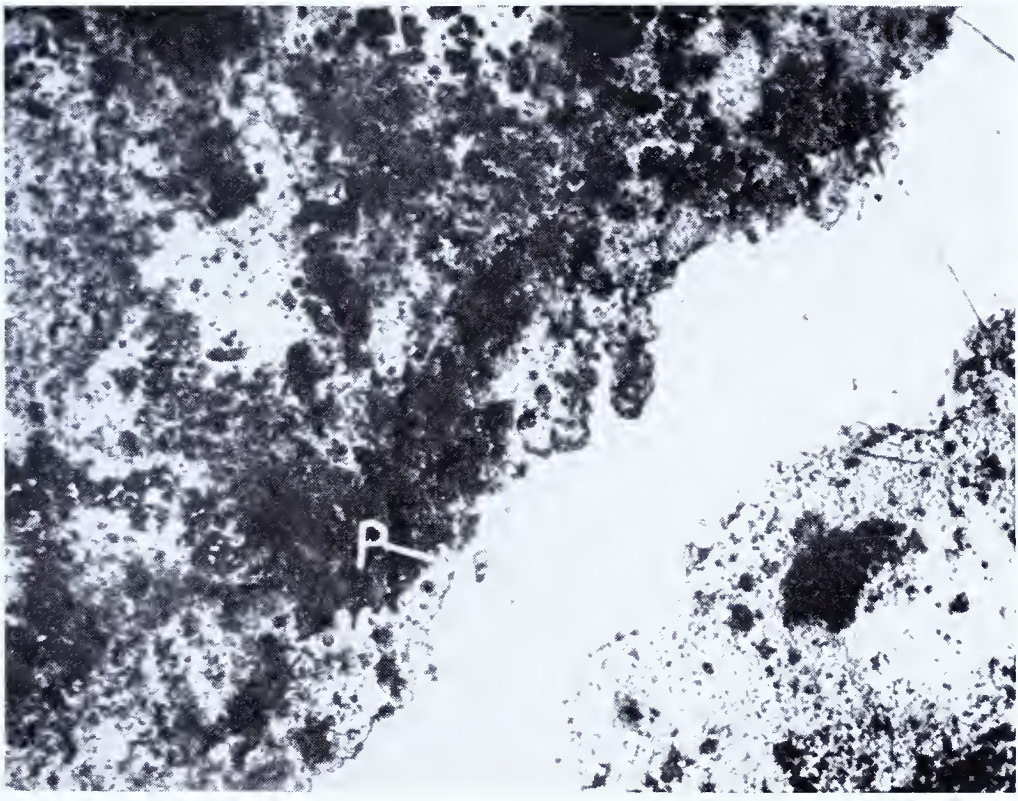
B. Limonite (gray) irregularly replacing veined cryptomelane (white) in upper left. Quartz, "Q", relatively unreplaced.
(Magnification 75X. Specimen B.S.-3b.)

A. Cryptomelane, with botryoidal structure (white), replacing limonite (gray). Black band around botryoidal structure is a depressed zone in the limonite, caused by polishing. (Magnification 32X. Specimen B.S.-3b.)

B. Dark limonite selectively replacing cryptomelane (white) along colloform bands. (Magnification 50X. Specimen B.S.-5a.)

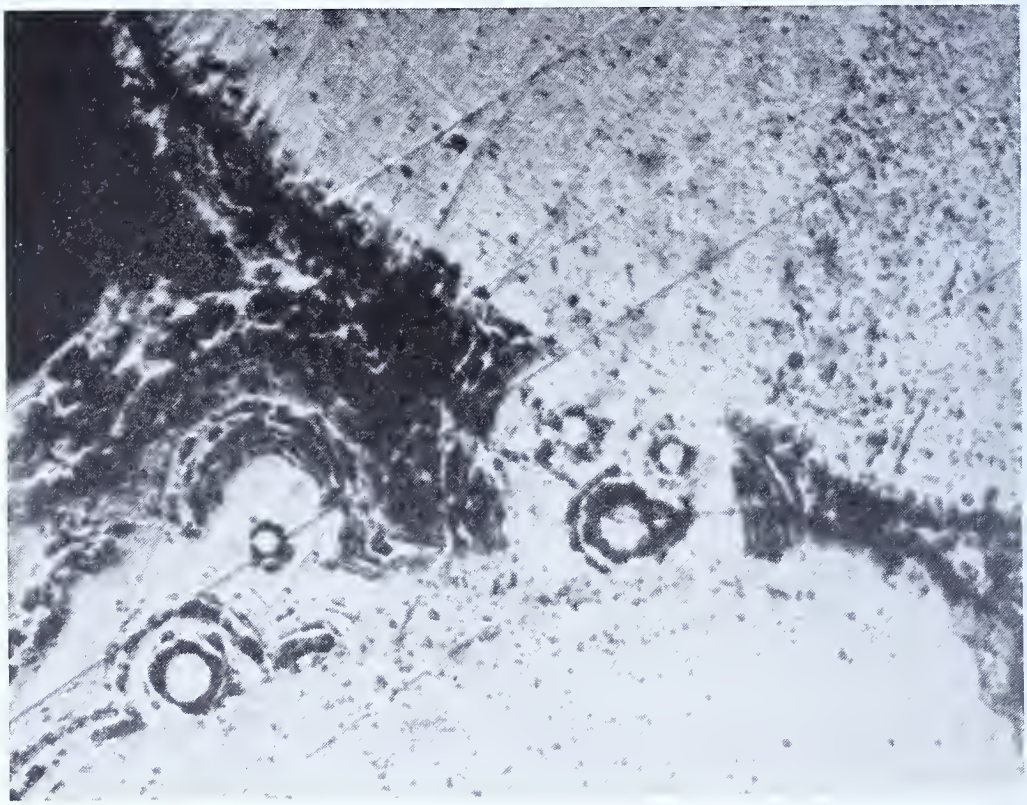


A. Dark limonite (light gray) replacing rust-colored limonite (dark gray), and both replacing quartz grains (black). Notice relatively complete replacement of quartz in areas of dark limonite. (Magnification 50X. Specimen B.S.-5a.)



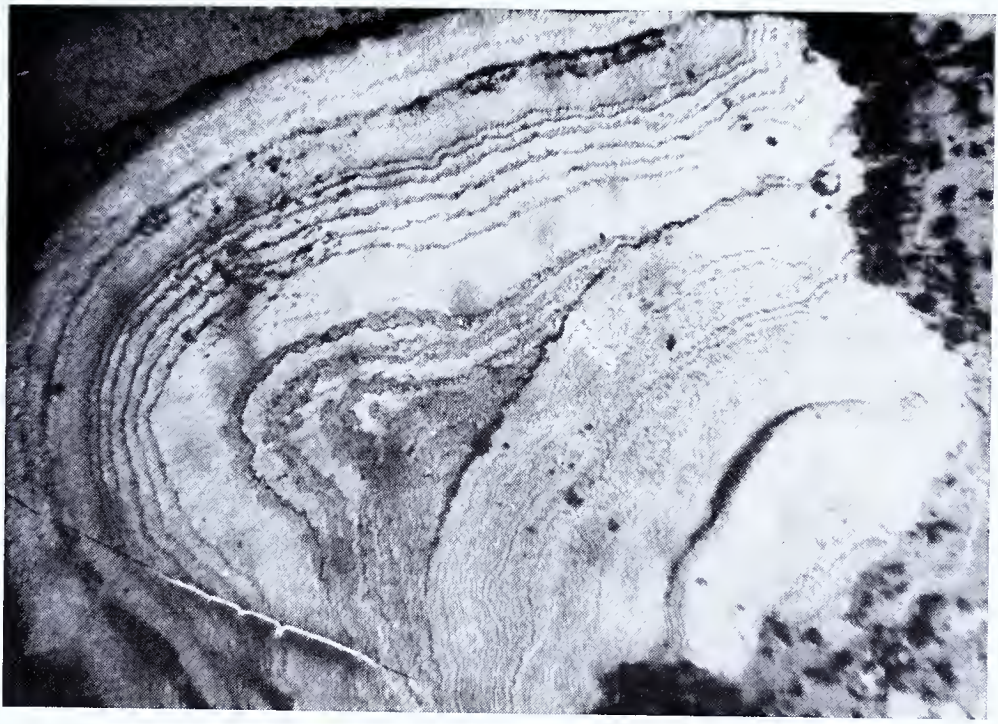
B. Vein of cryptomelane, "P", (white) cutting across dark limonite (light gray) and rust-colored limonite (dark gray). Dark limonite has replaced most of rust-colored limonite and quartz (black). (Magnification 64X. Specimen B.S.-5b.)

A. Early stage of growth of iron oxide stalactites, showing separated concentric "sheets" filled with clay, or hollow. Stalactites are growing along periphery and at junction of two botryoidal structures. (Magnification 75X. Specimen B.S.-6.)

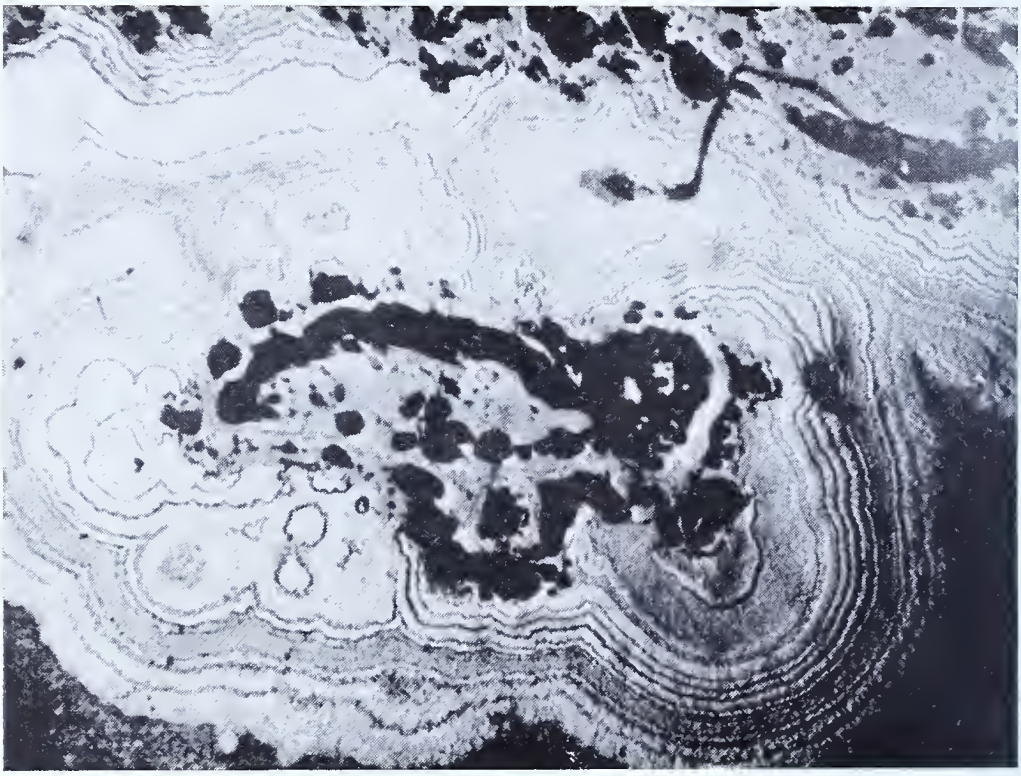


B. Cross section of a larger iron oxide stalactite, showing coalescence of "sheets" and disappearance of concentric structure. Scratches on surface are from poor polish. (Magnification 75X. Specimen B.S.-6.)

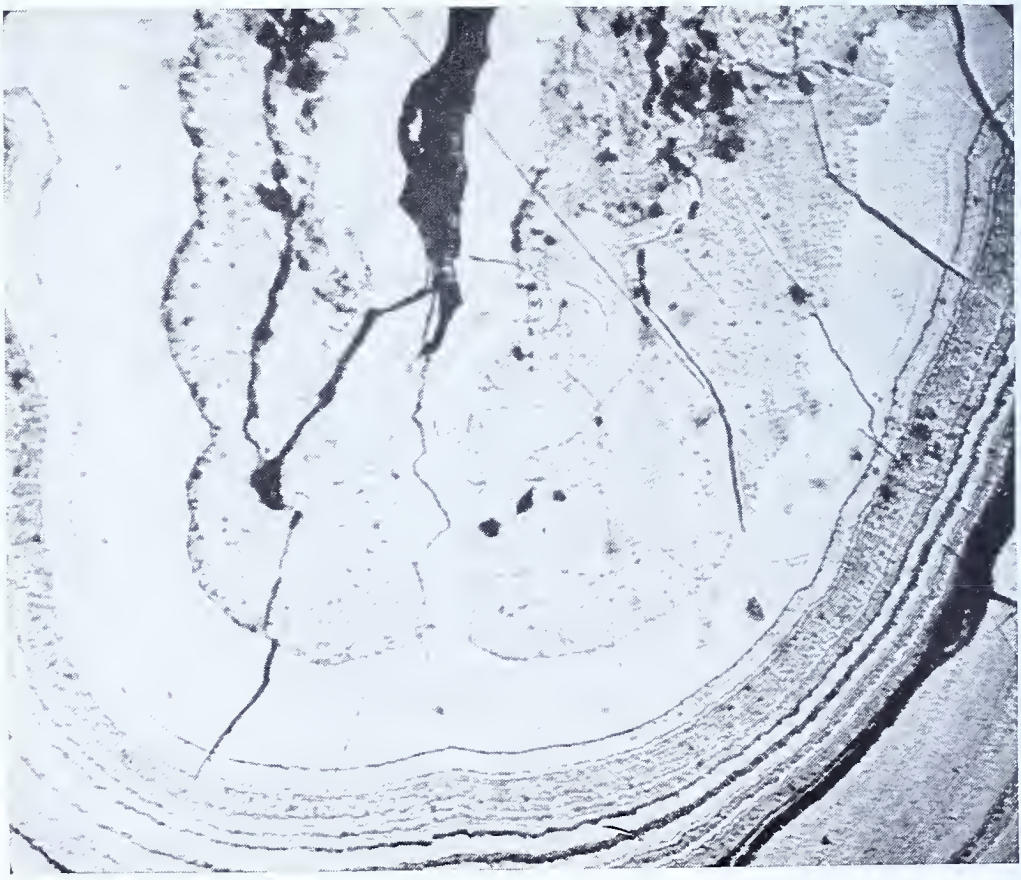
A. Colloform banded cryptomelane (white) replaced by vein of limonite (gray), which carries partly resorbed fragments of cryptomelane. (Magnification 32X. Specimen B.S.-8.)



B. Colloform banding and development of botryoidal structure in cryptomelane. Notice the truncation of some of the bands (left center) by second generation cryptomelane. (Magnification 190X. Specimen B.S.-9a.)

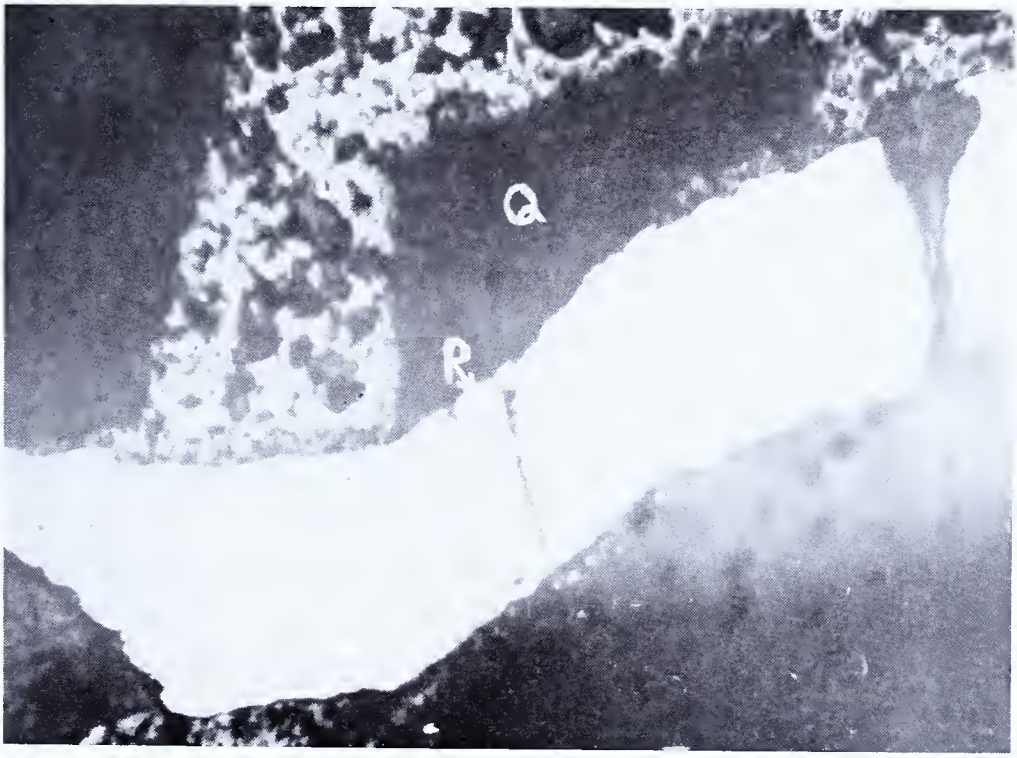


A. Intricate colloform banding in a botryoidal structure of cryptomelane (white). Some of the colloform bands are selectively replaced by limonite (gray). (Magnification 100X. Specimen B.S.-9a.)



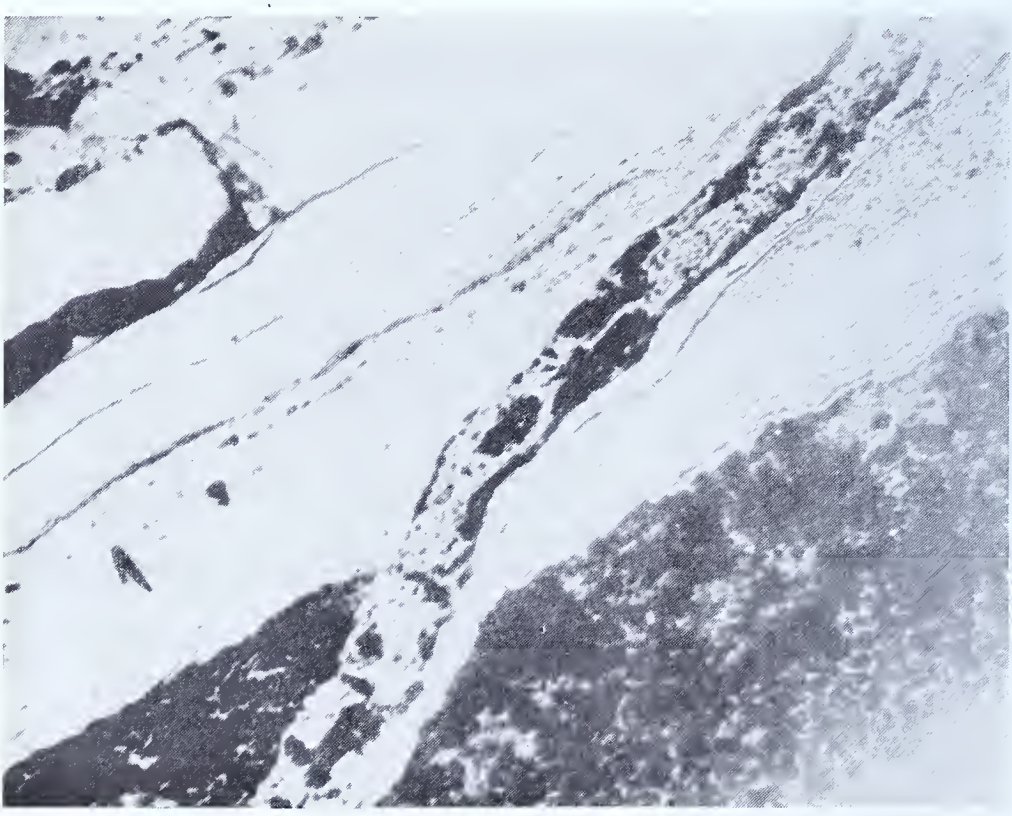
B. Colloform banded botryoidal structure of cryptomelane with well developed radial cracks. Notice later generation cryptomelane (white) intruding and replacing central area (gray) along a radial crack. (Magnification 50X. Specimen B.S.-9a.)

A. Colloform banded vein of manganese oxide. Cryptomelane (white and dark gray) is earlier and has contracted along radial cracks. Manganite (light gray) intrudes along cracks and cuts across the cryptomelane. (Magnification 50X. Specimen B.S.-9a.)

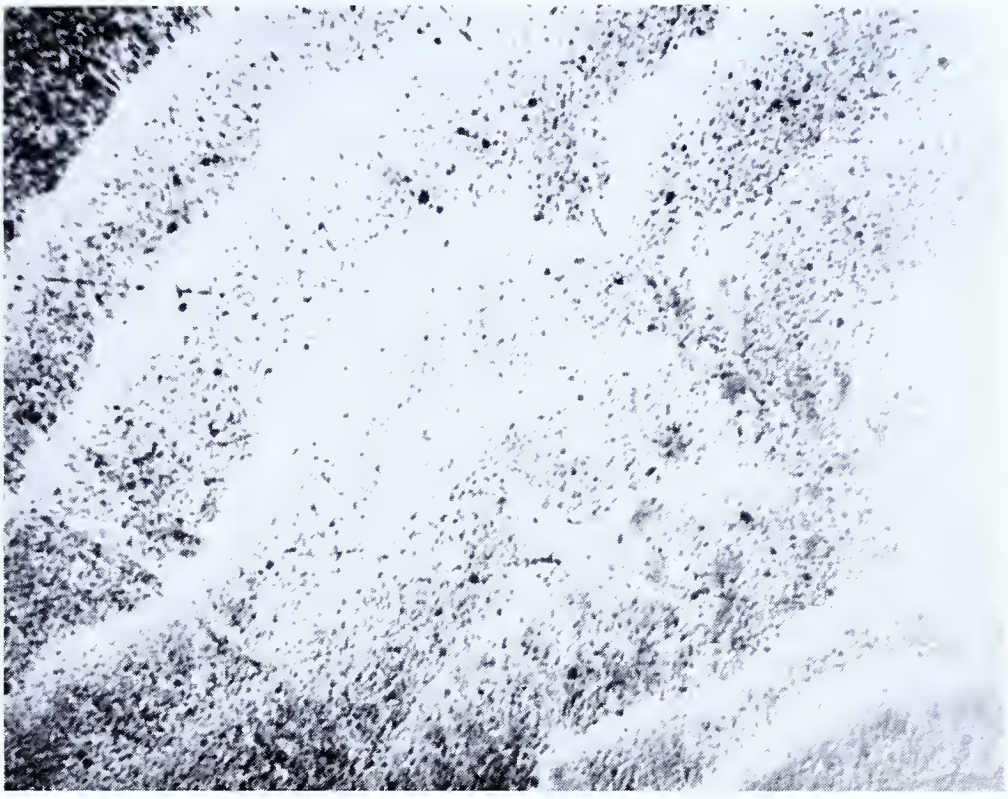


B. Vein of cryptomelane, "P", cutting across large quartz grain, "Q", and mixed limonite and quartz, which surrounds the larger quartz grain. Black band across cryptomelane is a polishing crack filled with rouge. (Magnification 75X. Specimen B.S.-9b.)

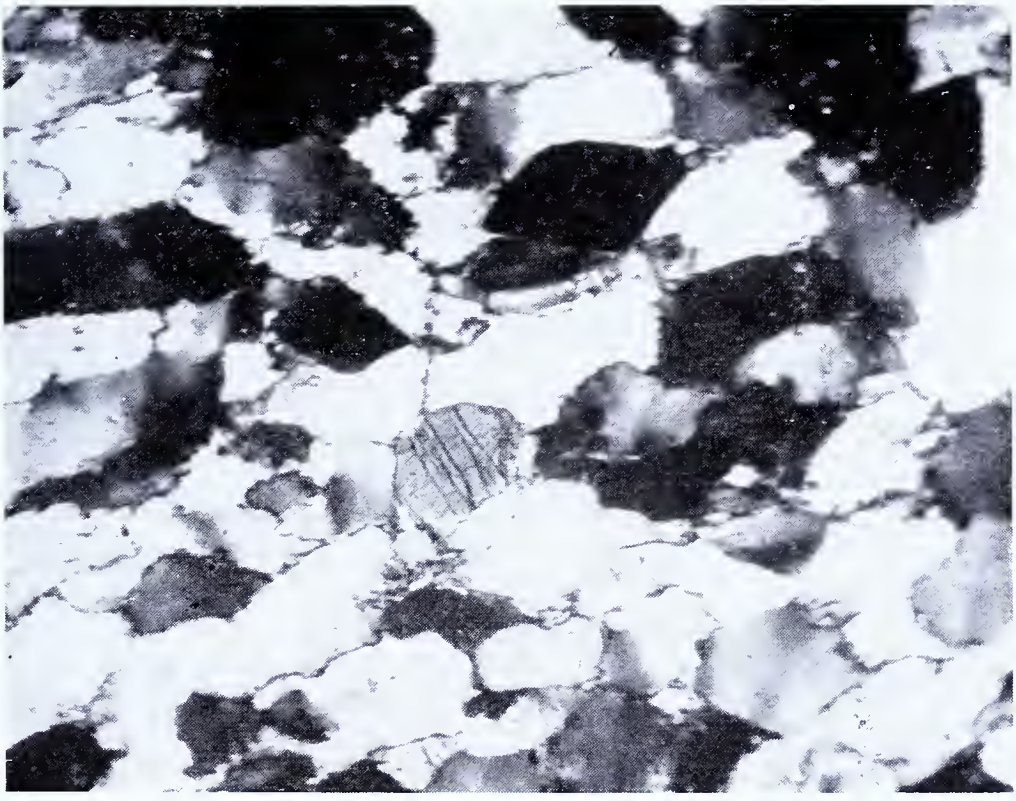
A. Vein of manganite (white) cutting through and replacing dark limonite vein (light gray). Mottled texture formed by replacement of quartz (black) by early stage rnst-colored limonite (dark gray). (Magnification 75X. Specimen B.S.-9c.)



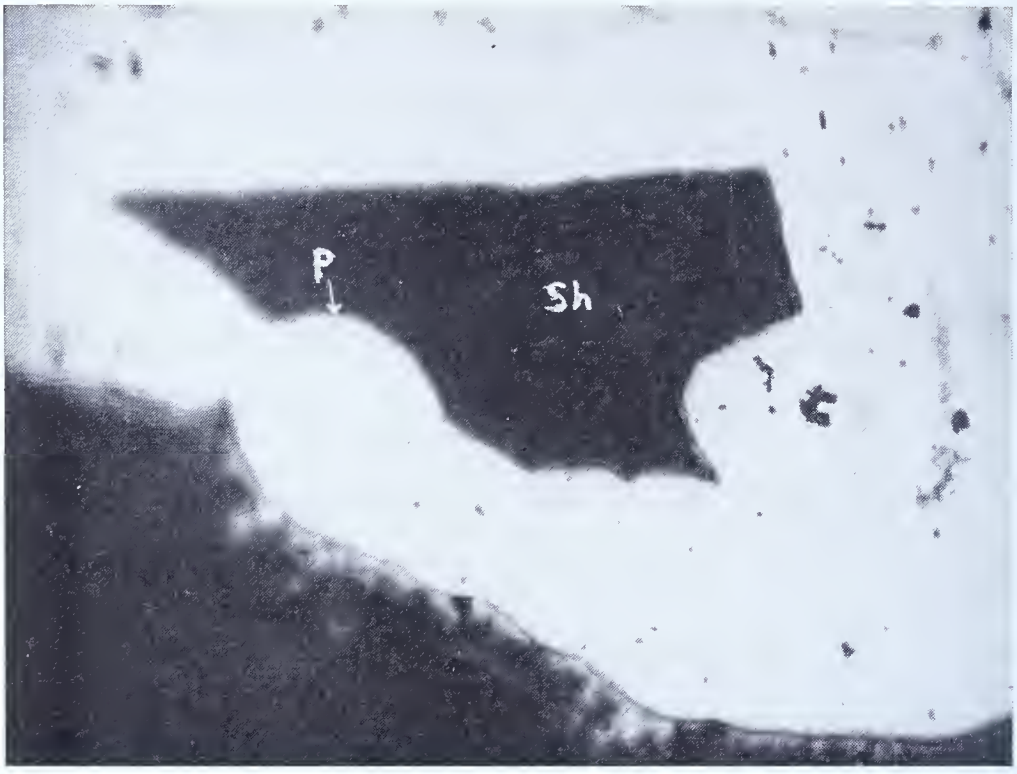
B. Vein of black limonite cutting across colloform banded cryptomelane and mottled mass of quartz and rust-colored limonite. (Magnification 48X. Specimen B.S.-9d.)



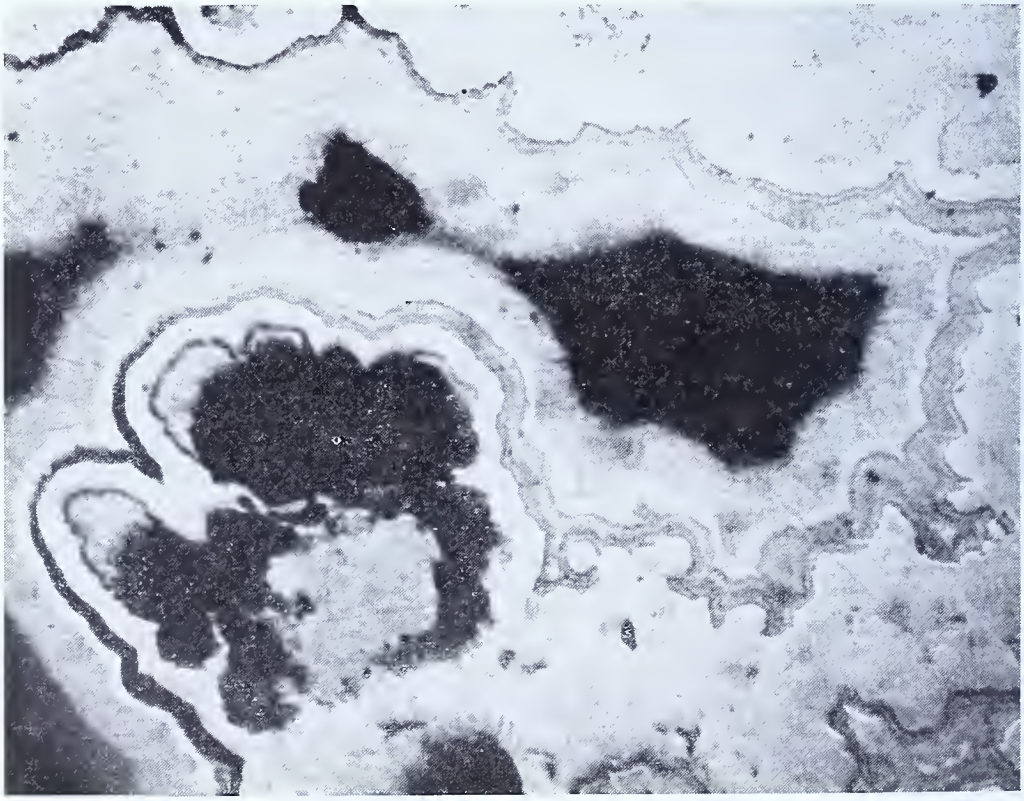
A. Colloform and granular texture in cryptomelane.
(Magnification 48X. Specimen B.S.-10.)



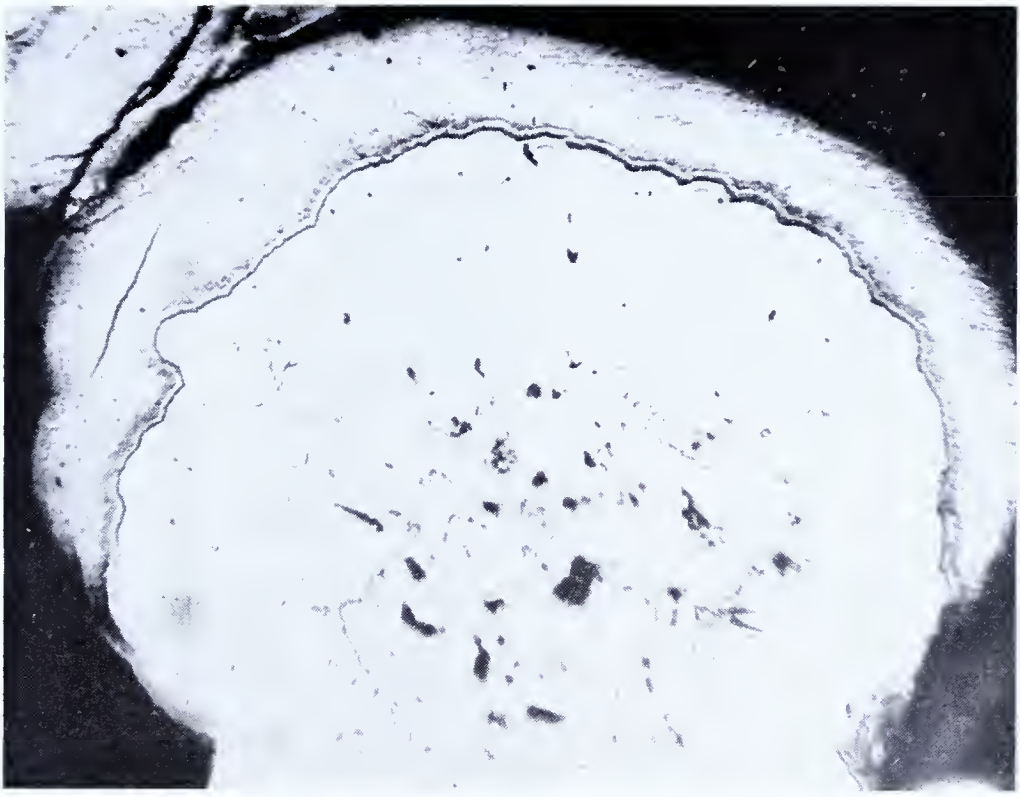
B. Quartzitic texture of Antietam sandstone. All grains are quartz, except for one cross-fractured, gray tonrmaline grain in center. Grains elongated parallel to bedding.
(Magnification 120X. X-nicols. Specimen B.S.-11.)



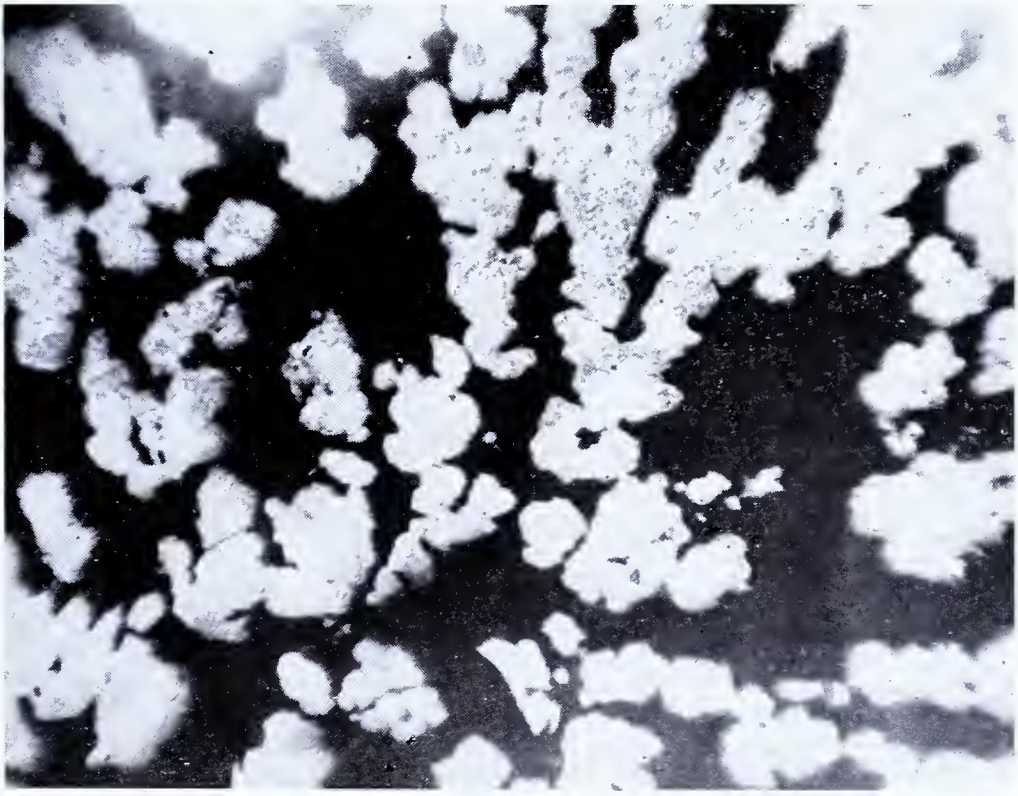
A. Cryptomelane, "P", replacing fragment of Mauch Chunk red shale, "sh", by deep embayments. Notice small residual unreplaced quartz grains (black). (Magnification 48X. Specimen H-1.)



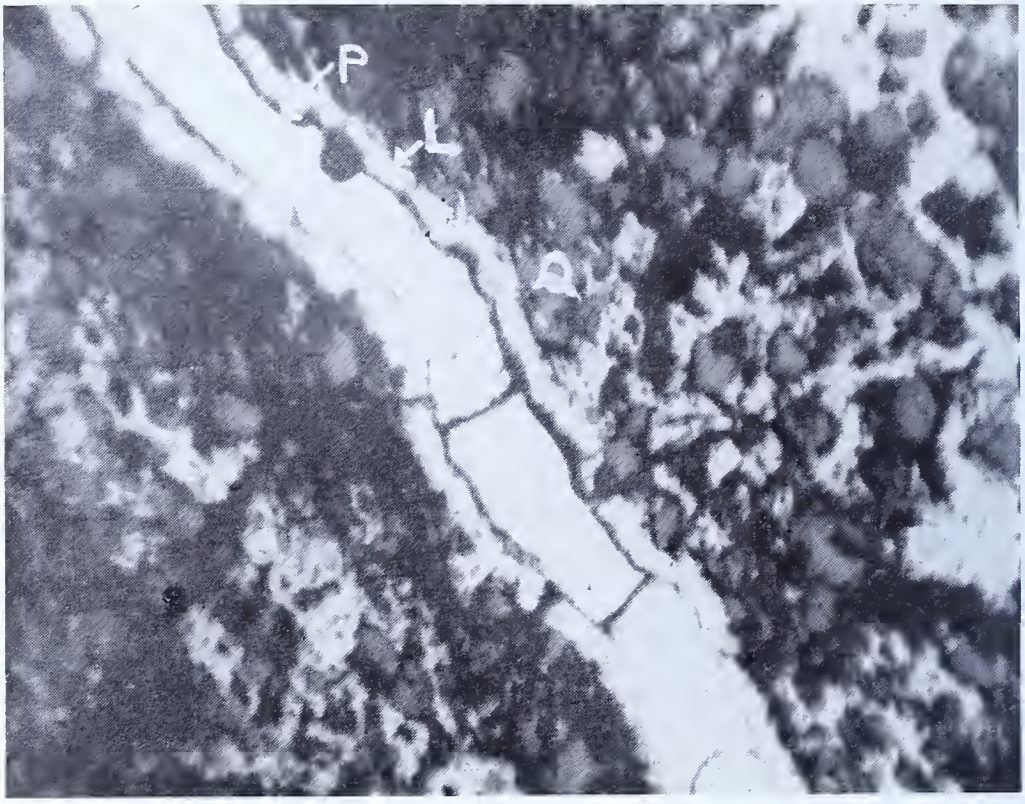
B. Colloform banded cryptomelane, possibly in two generations (white and gray). Botryoidal structure developed. Black areas are depression in polished surface. (Magnification 75X. Specimen H-2a.)



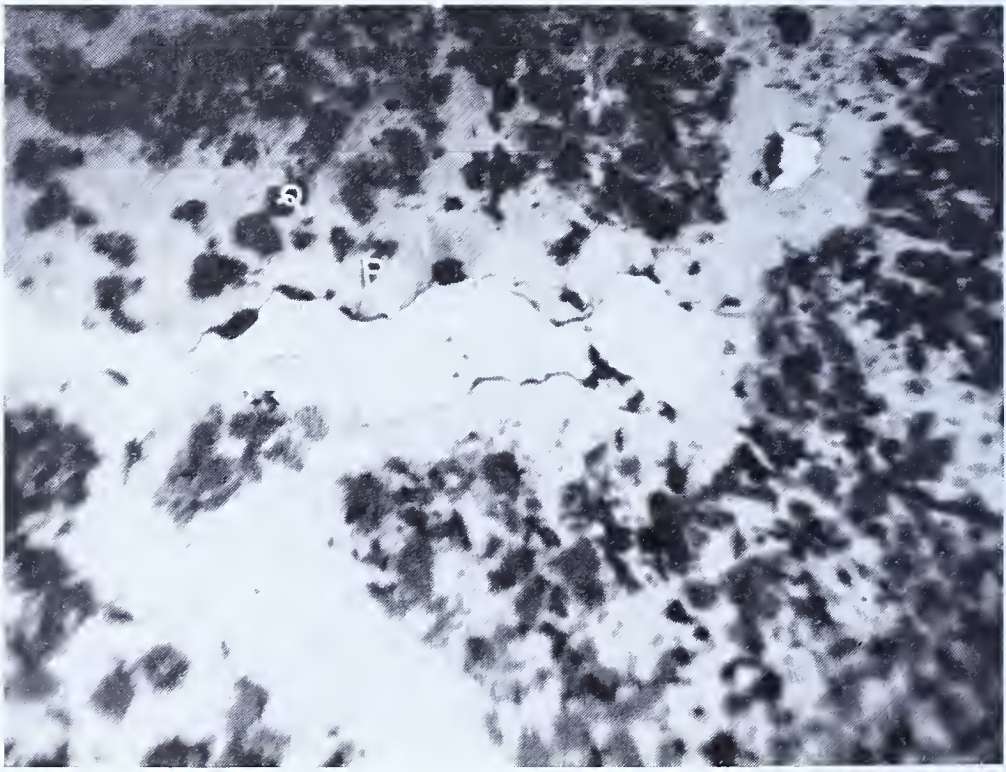
A. "Growth cap" of second generation cryptomelane on botryoidal structure of first. (Magnification 75X. Specimen H-3a.)



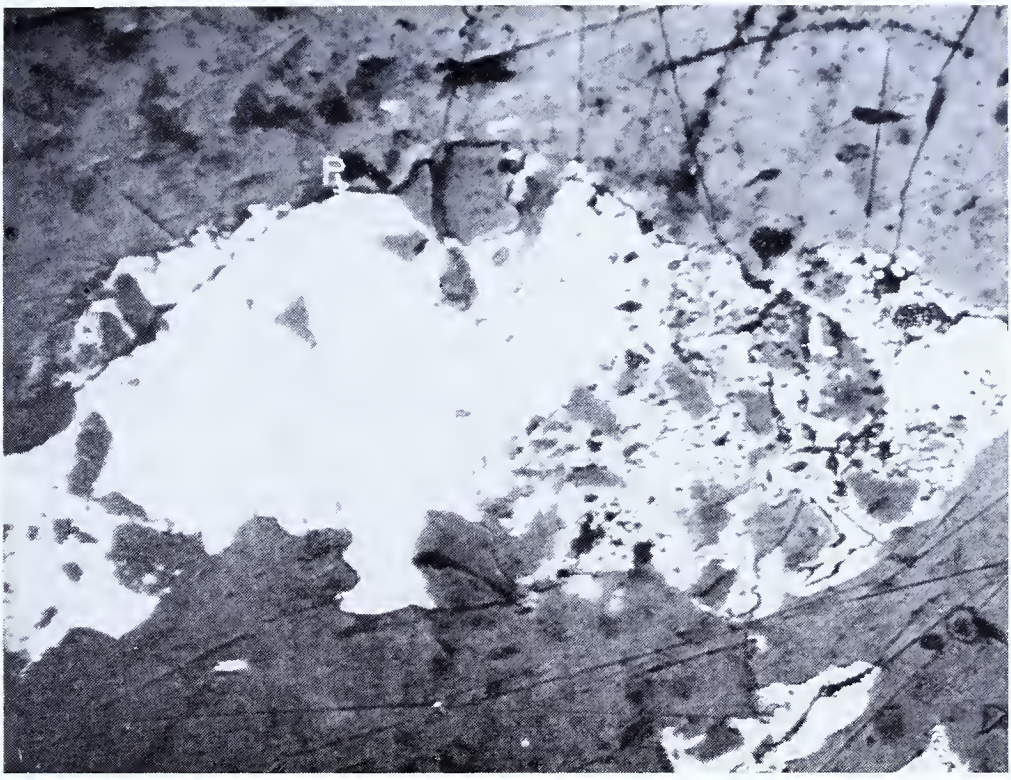
B. Dendritic structures of cryptomelane partly coated with sooty pyrolusite. A banded zone of pyrolusite lies at the edge of the dendritic structures. (Magnification 75X. Specimen H-3b.)



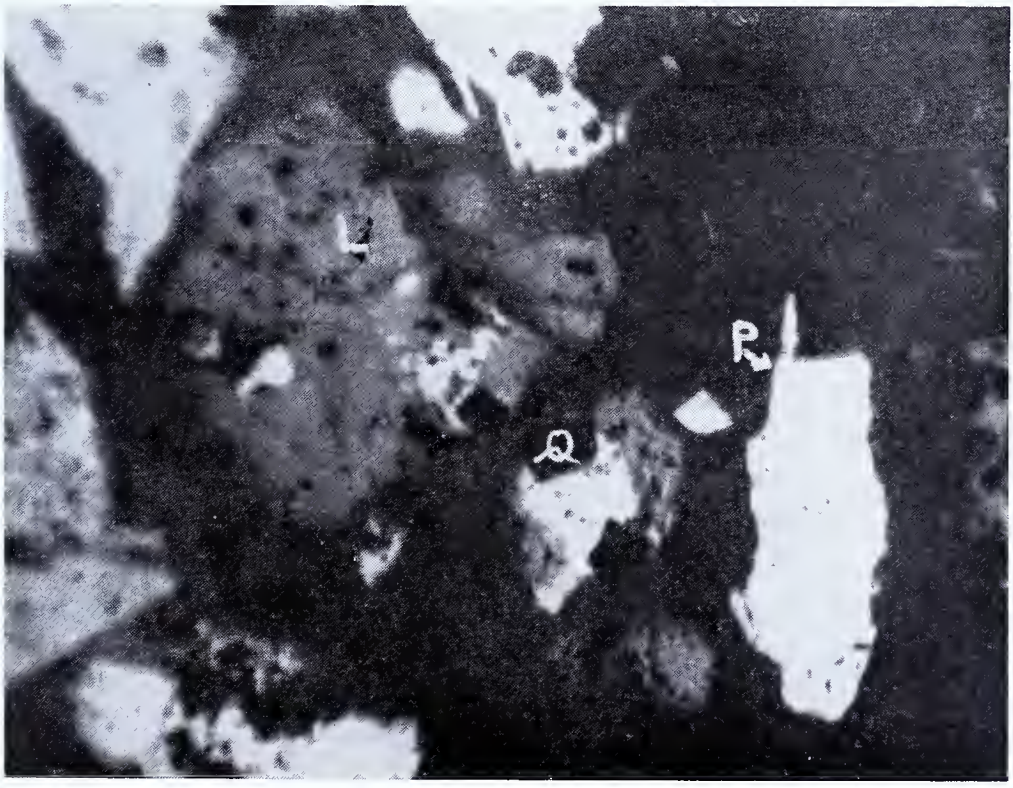
A. Vein of cryptomelane, "P", intruded into reopened vein of limonite, "L", which cuts across a mottled mass of mixed quartz, "Q", and limonite. (Magnification 180X. Specimen H-4.)



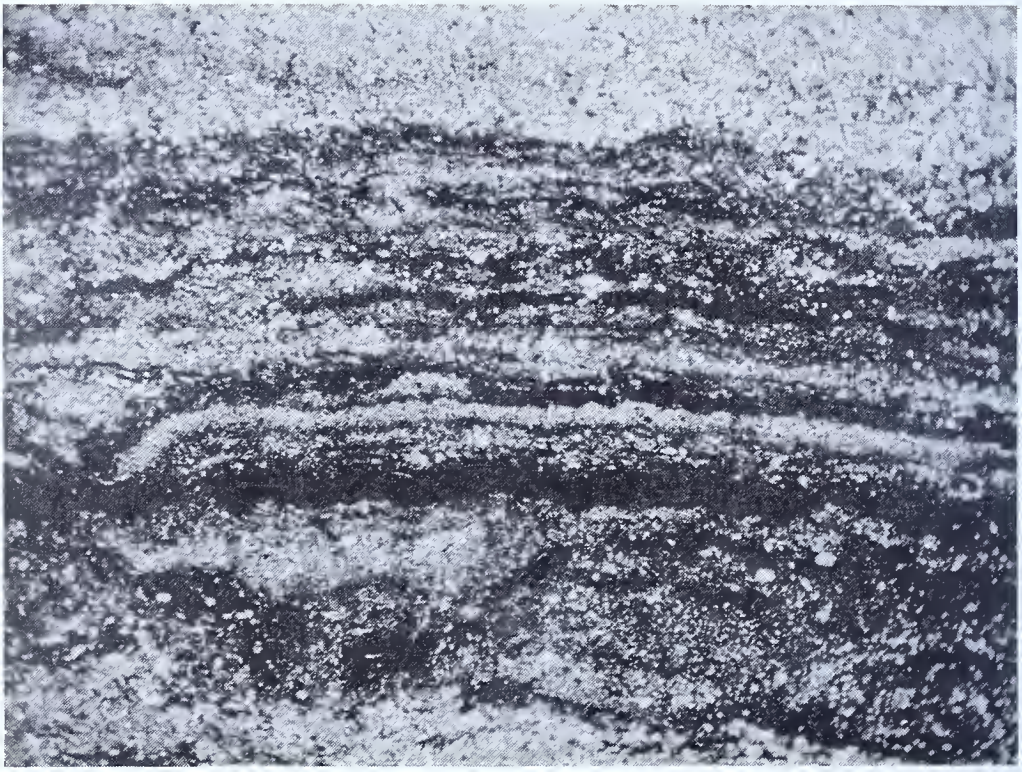
B. Irregular shaped vein of cryptomelane, "P", replacing the central part of an irregular limonite vein which "spreads out", filling the space between unreplaced quartz grains, "Q".
(Magnification 150X. Specimen H-7.)



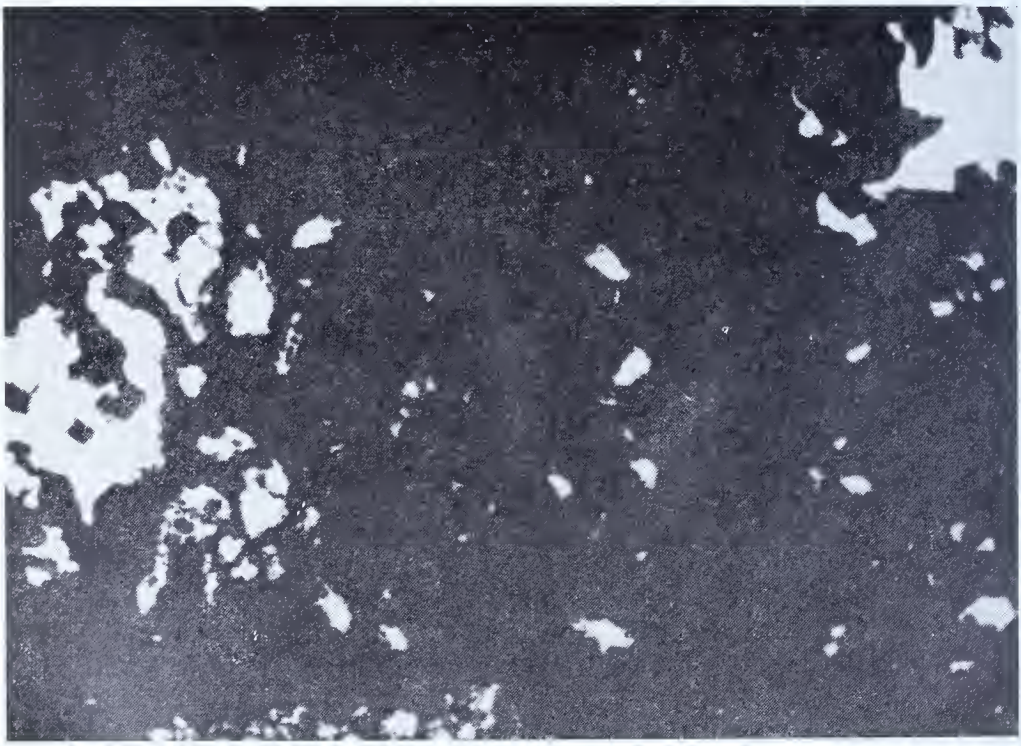
A. Fragment of ore crushed to approximately one-sixteenth inch size and mounted in plastic. Cryptomelane, "P", contains objectionable gangue, quartz, "Q", and limonite, "L" (grey).
(Magnification 75X. Specimen H-5.)



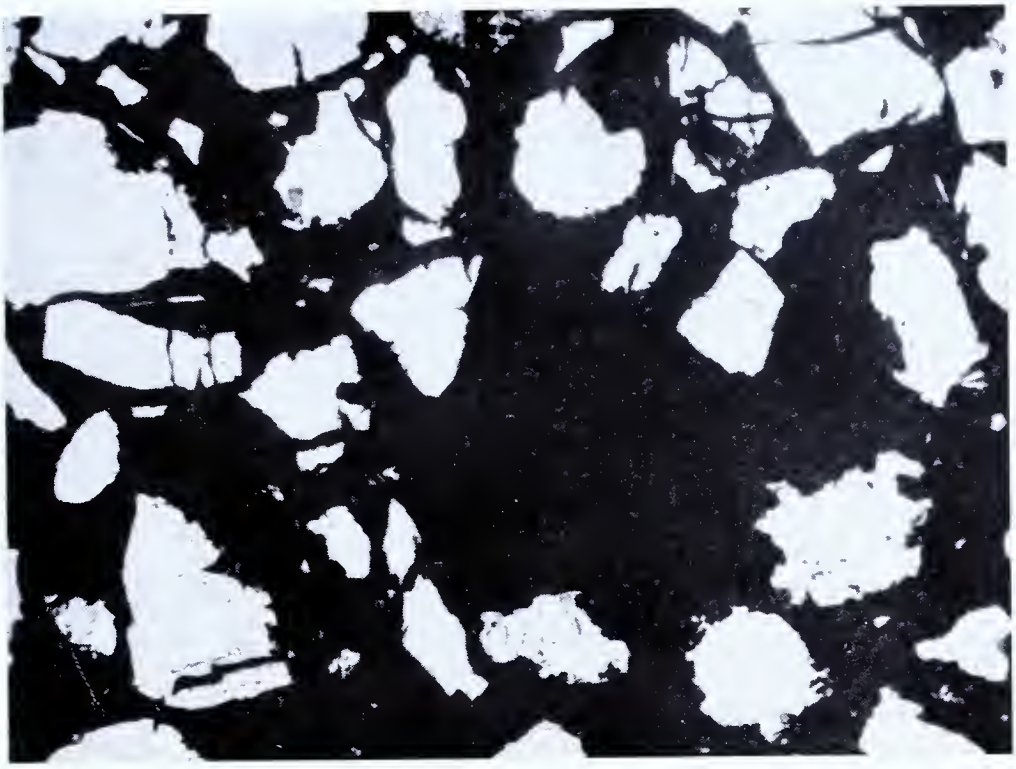
B. Fragments of ore crushed to 200 mesh, showing fairly complete separation of cryptomelane, "P", from the gangue minerals, quartz, "Q", and limonite, "L". (Magnification 175X. Specimen H-6.)



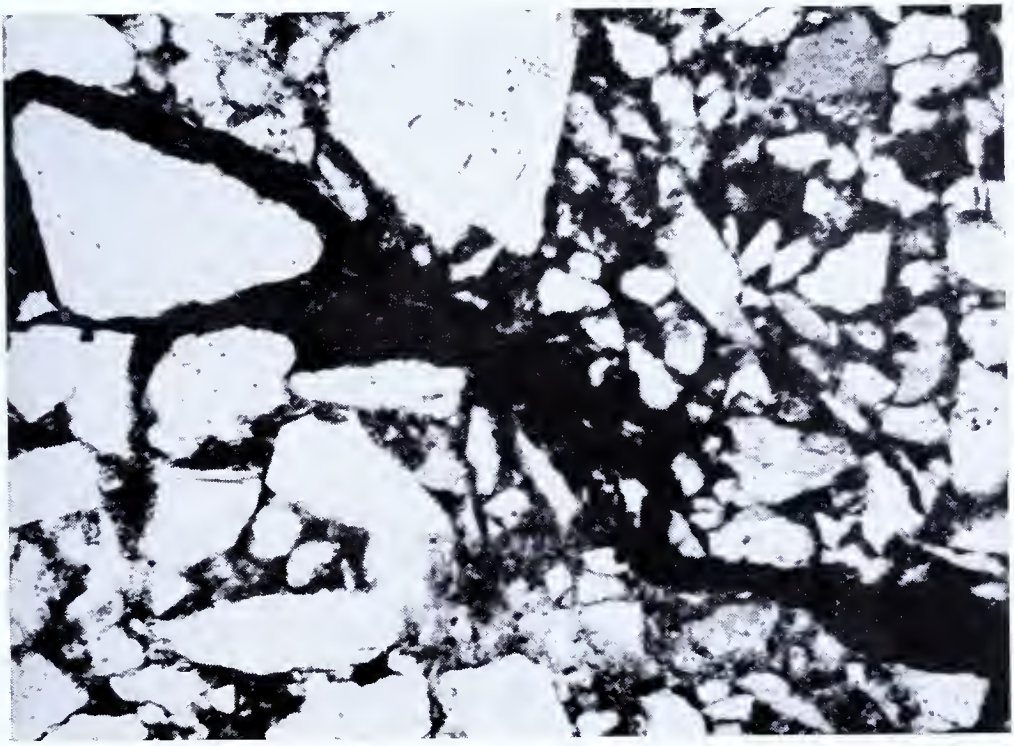
A. Laminations in Mauch Chunk red shale. Black laminae are primary iron oxide. Quartz and sericite comprise the rest of the mass. Notice the "slumping" or "contemporaneous deformation" on the left. (Magnification 50X. Thin section. Specimen S.V.-9.)



B. Manganese oxide (black) almost completely replacing Antietam sandstone. Notice the ragged, corroded edges of the quartz. (Magnification 110X. Thin section. Specimen W-1.)

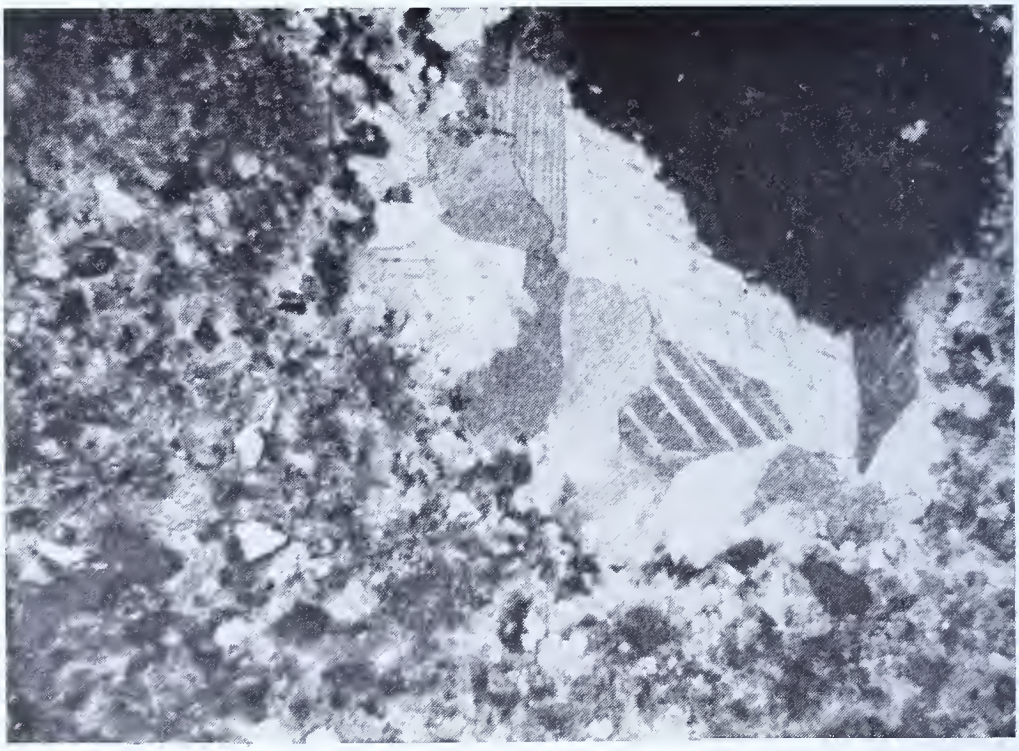


A. Manganese oxide completeley impregnating pore-space of Oriskany sandstone and partially replacing sand grains along corroded edges. (Magnification 110X. Thin section. Specimen O-1.)

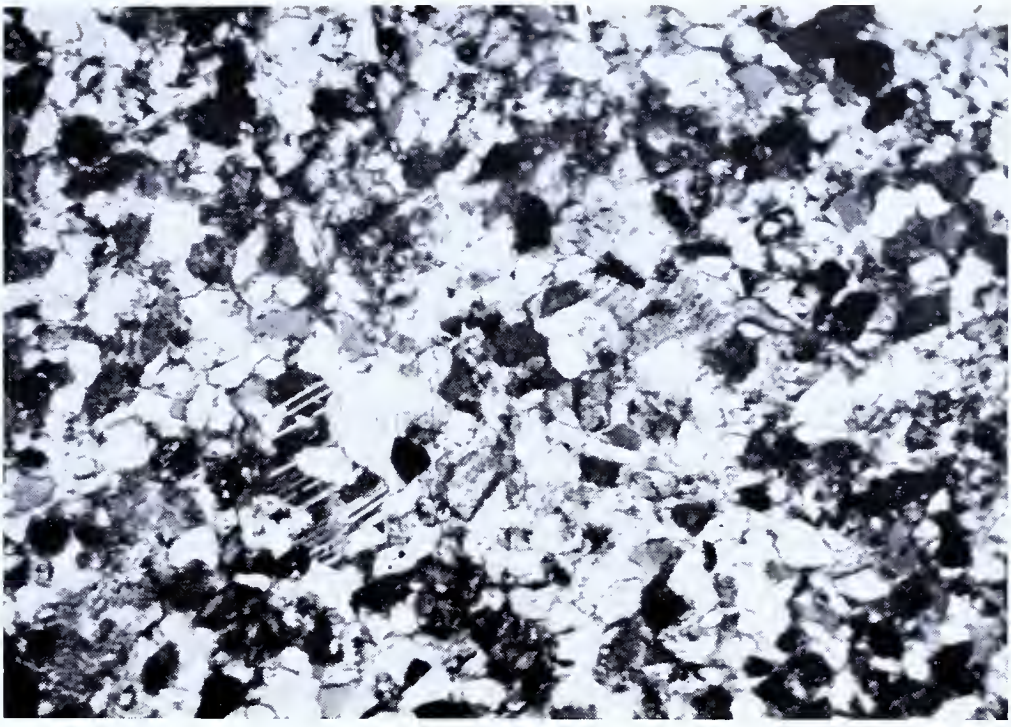


B. Vein of manganese oxide (black) in sandy underclay. Large white grains are quartz and small white grains are quartz mixed with a minor amount of sericite. Notice that the edges of some of the quartz grains along the vein are corroded.
(Magnification 110X. Thin section. Specimen Lo-1.)

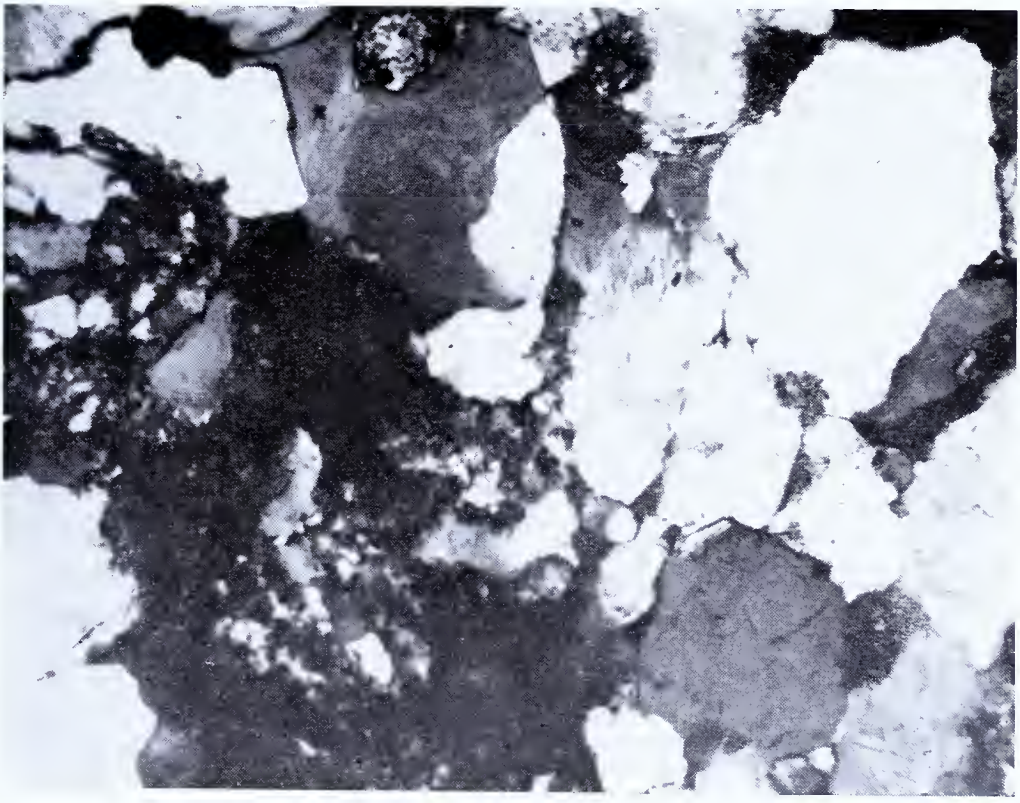
A. Texture of intraformational conglomerate in Mauch Chunk shale. All fragments are shale; all are rounded. The slight elongation of grains is parallel to bedding.
(Magnification 75X. Thin section. Specimen S.V.-6.)



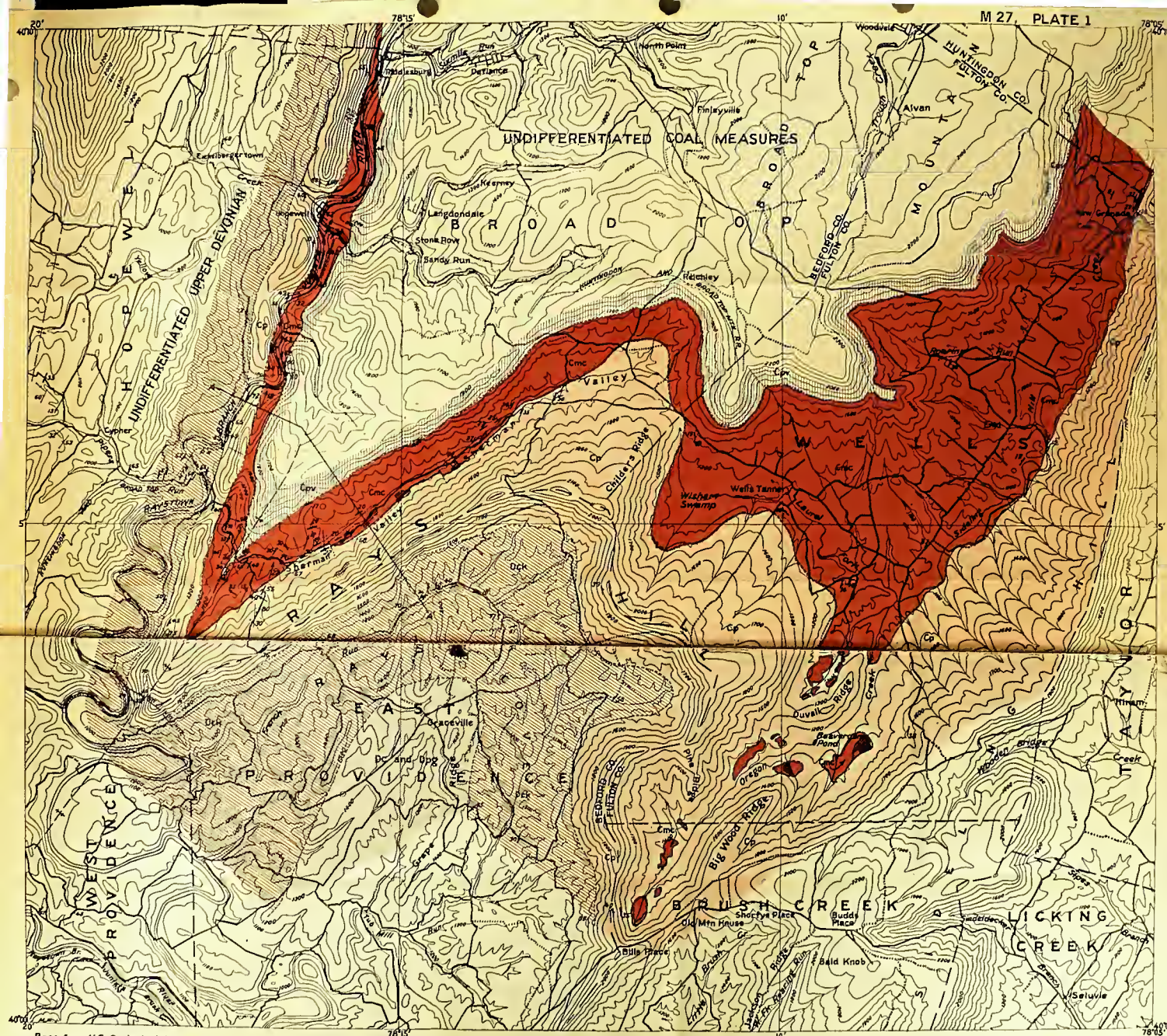
B. Texture of matrix of intraformational conglomerate in the Mauch Chunk shale. Small grains are mixture of carbonate, quartz, and sericite. Large carbonate grain (calcite) shows excellent cleavage. X-nicols. (Magnification 120X. Thin section. Specimen S.V.-6.)



A. Texture of red limestone in basal beds of Mauch Chunk shale. Closely locked angular grains of quartz and carbonate. X-nicols. (Magnification 110X. Thin section. Specimen S.V.-L.A.)



B. Texture of Pocono sandstone. Large sub-rounded grains are all quartz. Notice secondary growth of quartz on grain above center. Finer, matted matrix is composed of quartz and sericite. X-nicols. (Magnification 120X. Thin section. Specimen S.V.-10.)



EXPLANATION

Sedimentary rocks

- Gravel bed cemented by manganese oxide — PENNSYLVANIAN QUATERNARY
- Cpv — Pottsville formation disconformity — PENNSYLVANIAN QUATERNARY
- Cmc — Mauch Chunk formation disconformity — MISSISSIPPIAN
- Cp — Pocono sandstone — MISSISSIPPIAN
- Dck — Catskill formation — DEVONIAN
- Dc and Dpg — Chemung and Portage formations — DEVONIAN
- Areas of manganese float
- Known geologic boundary and dip of contact
- Inferred geologic boundary
- Strike and dip of beds
- Strike and dip of joints (Each one equals approximately 20 joints)
- Strike of vertical joints (Each one equals approximately 25 joints)
- Strike and plunge of lineation (Intersection of bedding and cleavage) (Each symbol equals approximately 25 readings)
- Lineation showing strike and plunge of striae in bedding planes (A-C plane)
- Strike and dip of known fault and strike of striation
- Strike of inferred fault
- Anticlinal axis
- Synclinal axis
- Mine from which manganese oxide ore has been produced
- Prospect (Shaft, drift or pit)

Base from U.S. Geological Survey Topographic maps of Everett and Broad Top quadrangles.

GEOLOGIC MAP OF THE SHERMAN VALLEY AREA BEDFORD COUNTY

Scale 0 1 2 3 MILES

Contour interval 100 Feet
Datum is mean sea level

Geology by Richard M. Foose
PENNSYLVANIA GEOLOGIC SURVEY
1945

PENNSYLVANIA GEOLOGIC SURVEY

PLATE II

GEOLOGIC MAP AND CROSS SECTION
OF
THE READING BANKS ORE PIT

EXPLANATION

Buff clay and earth float, with Antietam quartzite

White clay south side of pit
White clay plus some loose ore (north side)

Massive limonite Spsilomelane ore with some interbedded clay

Strike and dip of ore beds

Scale
0 50 100 150 200 250 FEET

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

Section along A-A

READING BANKS ORE PIT

N